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Sec IRHdbk P 3-96

NWC TP 4624

COMPILATION OF SPECTRAL EMITTANCES OF BACKGROUND AND TARGET CONSTITUENTS IN THE 8- TO 14-MICRON RANGE

by

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ABSTRACT. A search of the unclassified literature for 8 to 14 micron spectral emittance information on infrared background and target materials resulted in a comprehensive compilation that is presented in this report. The report abstracts information published prior to October 1967 and concerns the room temperature spectral dependence of the emittance of various classes of materials. A large amount of data is available in the literature for certain material classes such as metals, paint coatings, and minerals, and representative data is here abstracted. Little information is available for the material classes of foliage, soils, plastics, and other synthetic building materials. All useable reported data on these materials is presented. The selection criteria for the inclusion of data is presented. Techniques commonly used to obtain emittance, absorptance, and reflectance data are outlined. A bibliography of open literature reports containing emittance data is presented.

NAVAL WEAPONS CENTER

CHINA LAKE, CALIFORNIA * SEPTEMBER 1968

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FOREWORD

The literature search resulting in this document was performed as a part of the program of the Naval Weapons Center in the field of infrared detection. The work was supported by Naval Air Systems Command under AIR TASK A3653301/216-1/F001-05-01.

This report was reviewed for content by L. W. Nichols.

Information presented herein is subject to refinement and expansion as further works are available.

Released by
N. E. WARD, Head
Aviation Ordnance Department
9 September 1968

Under authority of
THOMAS S. AMLIE
Technical Director

NWC Technical Publication 4624

Published by . . . . Aviation Ordnance Department
Manuscript 35/MS-271
Supersedes . . . . Inside Distribution Publication 2593
Collation . . . . . Cover, 96 leaves, DD Form 1473, and abstract cards
First printing . . . . 165 unnumbered copies
Security classification . . . . UNCLASSIFIED

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AD841158

INTRODUCTION

This report is a compilation of infrared spectral emittance curves of natural background and target materials. The data was abstracted from all sources, as referenced, that were available prior to October 1967. The intent of the report is to present in one information source all of the reported background and target spectral emittance data for the wavelength range of 8 to 14 microns, as subject to the selection criteria set forth below. In most cases, data is presented over the longer wavelength region of 1 to 25 microns.

The data compiled in this report pertains to materials at natural ambient temperatures, although the original experimental temperatures ranged from 200 to 650°K. It has been reported that, in the case of metals, emittance is not greatly altered over this temperature range (Ref. 31). A similar assumption is reasonable for other solid materials, as has been commented upon by several authors. Temperatures below and above this range are not of interest in this report, since natural objects rarely obtain such temperature extremes.

Radiation characteristics of water are not included in this report, since emission and reflection from water surfaces require more than a passing description. Unexplained effects exist for the infrared radiation emission of water, and several investigators are presently involved with the problem.

Emittance information for a given substance comprises a body of knowledge that may be used to determine whether this particular substance may be detected against a given background condition. Such knowledge is necessary to assist the investigator in determining whether a detection system will perform adequately in a given situation. The knowledge is also necessary to assist in determining the characteristics of new testing equipment.

However, many factors other than emittance influence the nature and characteristics of thermal emission. In a terrain environment, wind conditions that affect heat flow introduce a new set of parameters that can be critical in many situations (Ref. 2). In still air, phenomena exist that may affect contrast; for example, diffusion and convection that occur near the leaf surfaces of trees and plants (Ref. 5). Air and plant moisture content partially determine the detectable radiation from foliage. Emission from rocks is affected by particle size and surface roughness. Composition and surface condition of metals strongly affect spectral emittance. Below 6 microns, grain size and moisture content determine the characteristic emission from soils (Ref. 24). From data presented in this report, it appears that grain size is a significant factor in soil emission in the 8- to 14-micron region. Moisture content is probably a significant but less critical factor in soil emission in this region. Sky conditions present another important factor to

be considered in evaluating contrast between terrain and target features. Finally, atmospheric transmission must be considered.

In order that information on emittance measurements be as useful as possible, it is necessary to know characteristics of the material tested and the test method. A brief description of the test method used is presented with each graph contained in this report and a separate section is included to describe the apparatus used by several of the investigators to obtain the data compiled here.

Comparison of emittance curves obtained by different investigators, or comparison of test methods used with the same material, provide an indication of the accuracy and reproducibility of the data. A few examples of such comparisons are included.

SELECTION OF MATERIALS FOR COMPILATION

The information compiled by this report can be divided into five categories of materials: (1) minerals, rocks, and tuffs, (2) soils, sands, and dust coatings, (3) foilage, grass, and bark, (4) metals, and (5) paints.

Additional categories such as cloth, paving materials, wood products, and synthetic materials were initially outlined, however, little or no information was available in a form useful to this report. These subjects were either inadequately described in the available information, or they were not within the wavelength range of interest.

The choice of materials in this compilation of spectral emittances was made according to the following criteria:

1. Spectral emittances must include information in most of the 8- to 14-micron region.

2. Materials included should appear as part of a terrain background, as structural material, as a coating used on structures or vehicles, or as materials made or modified by man.

3. Measurements performed on the materials discussed in this report should be of a form useful in determining emittance. (Thus, normal spectral emittance and total diffuse emittance measurements were included when they were expressed as "percent of a known standard", but were not chosen if they were emittances relative to some ill-defined standard.)

4. Earlier data on emittance of materials disagreeing with later, more authentic data, was to be disregarded in making the selection of materials for the compilation.

MEASUREMENT APPARATUS AND TECHNIQUES

Measurement of thermal emittance, absorption, and reflectance requires different techniques depending on the temperature range considered. For high temperatures, methods of measurement by emission (heating the sample and monitoring the emitted radiation) are convenient and useful. However, for moderate and low temperature measurements (the range of interest in this report), reflection methods offer ease and accuracy of determination (Ref. 1). The problem in measuring emittances directly at moderate and low temperatures lies in the low signal generated by the difference in radiation levels between the sample and the surrounding mountings and equipment used.

Reflectance measurements are often accomplished by means of equipment such as that described by Bevans, Gier, and Dunkle (Ref. 3) and illustrated in Fig. 1. Other investigators have devised similar equipment. The equipment consists of a heated blackbody radiator, a water-cooled sample, and an infrared dispersion and detection system. The blackbody radiator is heated to approximately 1500°F and the sample is water-cooled to keep its emission well below that of the radiator. A disperser/detector such as a Perkin-Elmer Model 83 spectrometer is used to monitor the radiation reflected from the sample in comparison to the

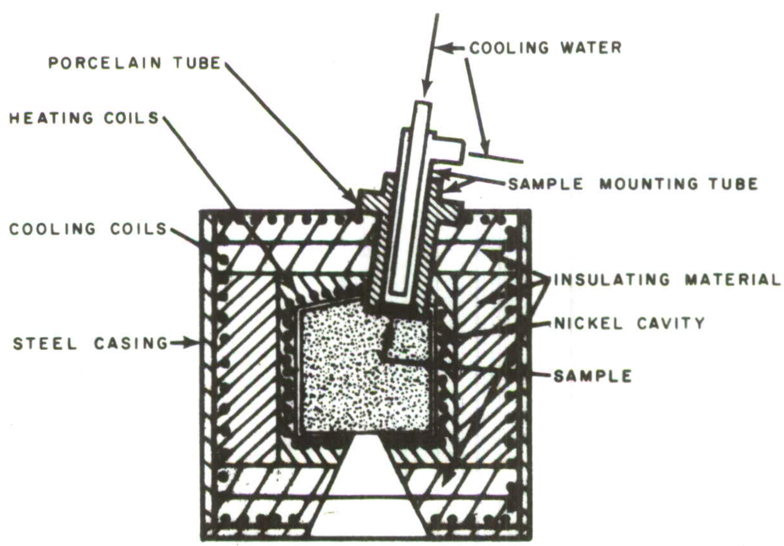

FIG. 1. Cross Section Representation of Heated Hohlraum.

heated reference cavity. From the configuration it is evident that normal reflectance is measured from the flat sample upon which radiation is approximately hemispherically incident.

Reference 12 offers an illustration (Fig. 2) describing reflectors used by several investigators to obtain reflectance data. It is noted that hemispherical and ellipsoidal reflectors are used since the materials may range in character from specular to diffuse. The measurements reported by Ref. 12 were actually performed with the system illustrated in Fig. 3.

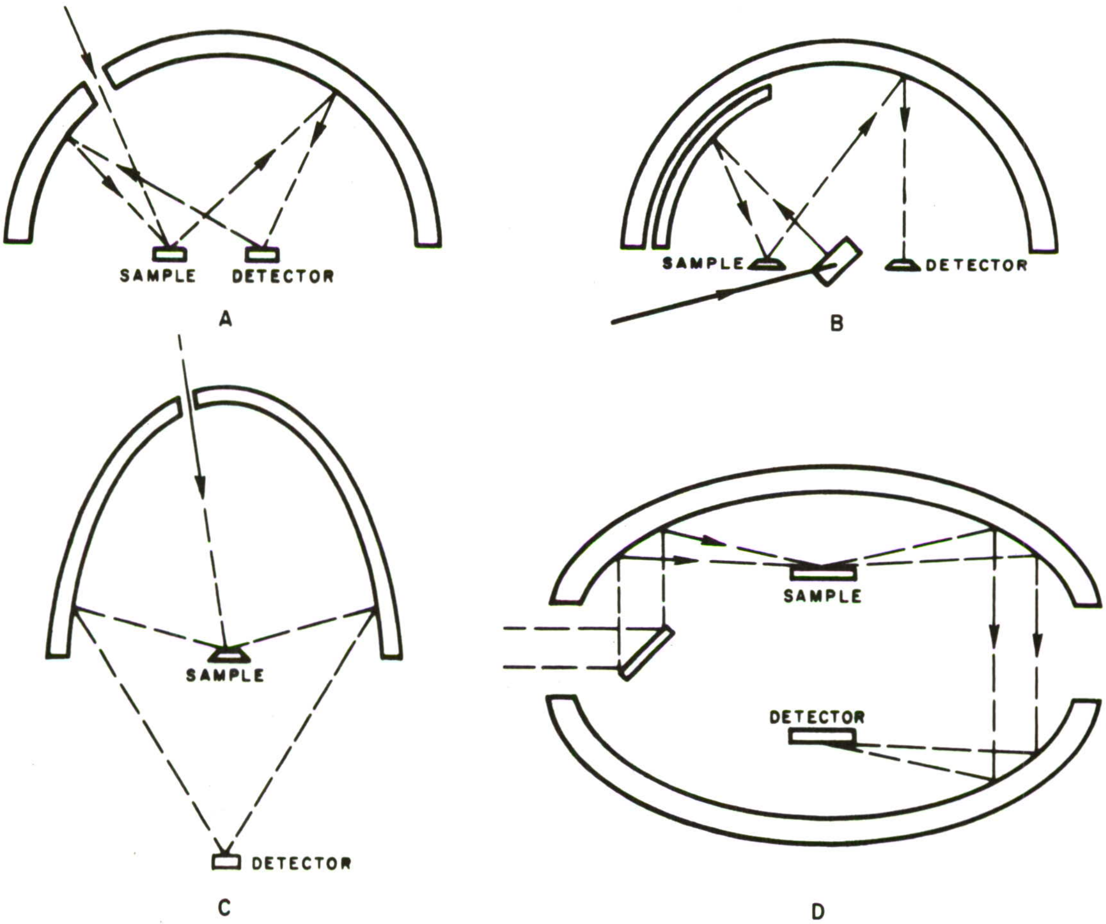

FIG. 2. Typical Integrating Arrangements for Reflectance Measurements. A. Paschen, 1899; B. J.V. White, 1951; C. N.B.S., 1959; D. Gier-Dunkle, 1955.

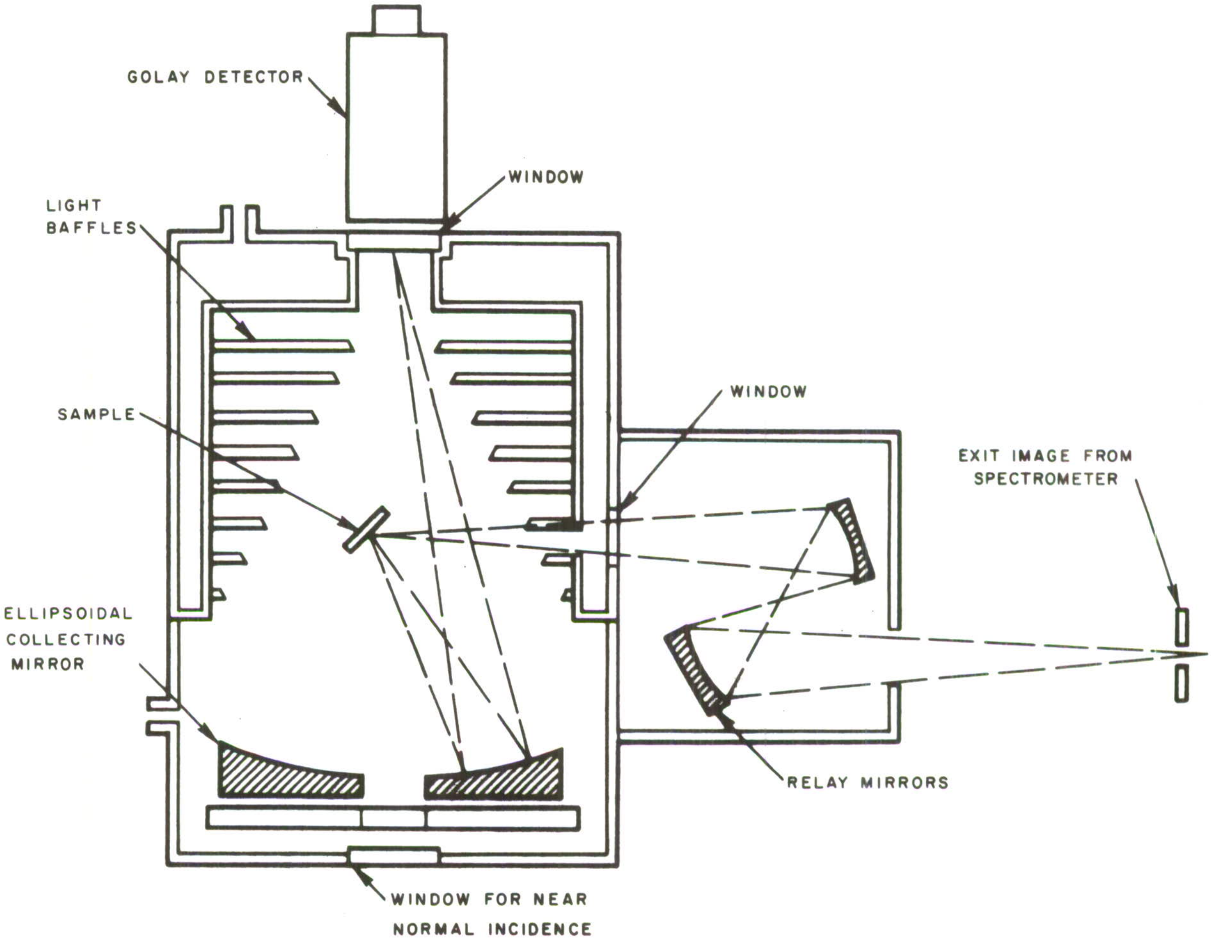

FIG. 3. Spectrophotometer Reflectance Attachment.

Emittance measurement systems are generally similar to that used by Seban (Ref. 32). As shown in Fig. 4, a sample heater and a reference cavity are mounted on a common axis with a mirror between. The mirror is automatically turned to pass radiation from the reference cavity, or the sample, to the exit slit in the side of the enclosure. The parabolic mirror at the exit slit collects the radiation and produces an image near the chopper. The radiation then passes through appropriate optics to a Perkin-Elmer Model 98 spectrometer, which is equipped with a thermocouple detector. Normal spectral emittance is the measured quantity.

Absorption analyses, such as performed by Lyon, often use the powdered alkali halide (KBr) pellet technique (Ref. 25). The sample under consideration is mixed at low concentration with KBr and pressed into a clear pellet. In Lyon's study, excellent response was obtained for KBr pellets containing silicate when the concentration of the sample was from 0.15 to 0.25%.

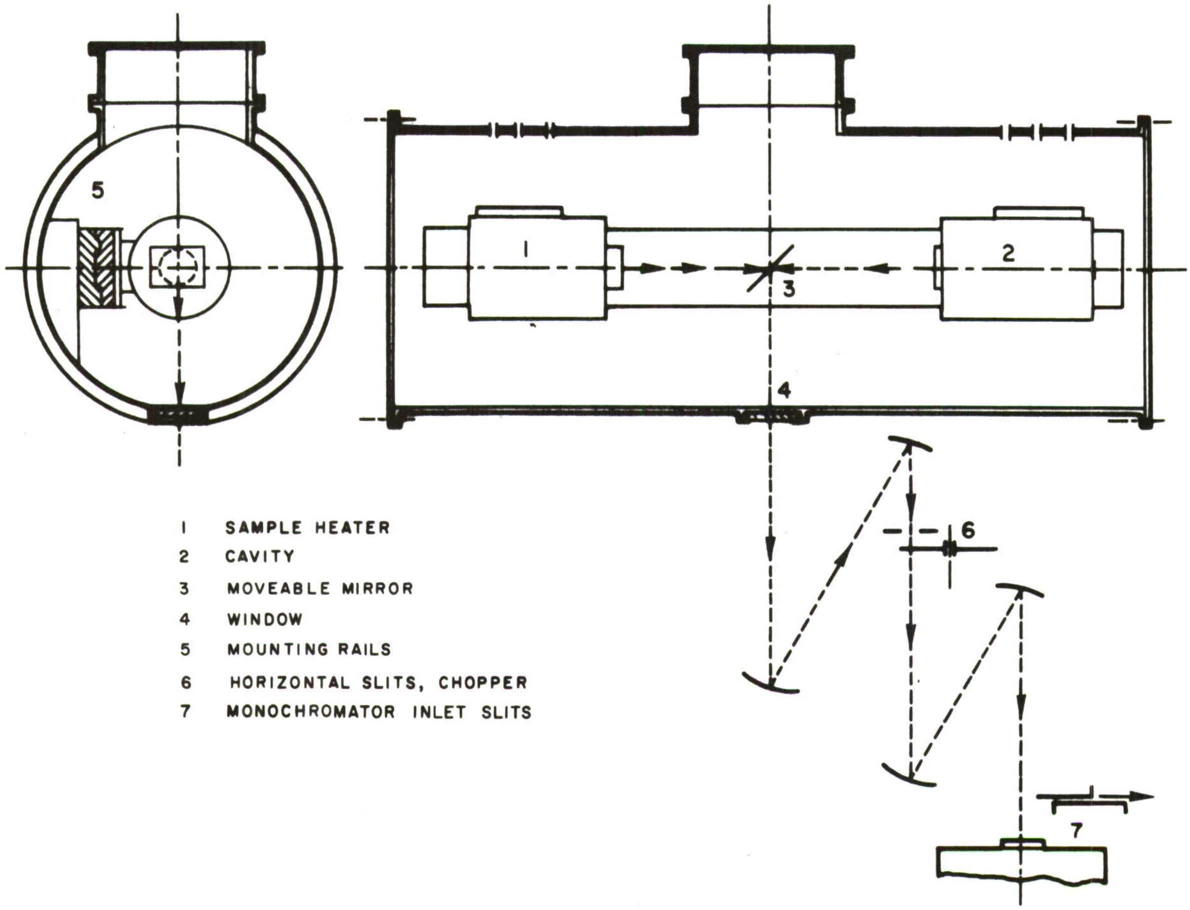

FIG. 4. System for Emittance Determination.

Precise agreement between KBr pellet absorption measurements and converted reflectance measurements of the same material should not be expected. The disagreement between the resulting spectra is fundamental and is due to the different mechanisms of absorption and emission of powdered and solid samples (Ref. 25, p. 39).

DATA TRANSFORMATION

In many instances the emittance measurements presented by the individual authors were produced from reflectance or absorptance information using Kirchoff's law for opaque objects:

absorptance = emittance

and

emittance = 1- reflectivity.

In other cases, the present authors have transformed the reported data into emittance values using the above relations. Such cases of transformation are noted directly, since each graph shown mentions the form in which the original author presented his data.

DEFINITIONS

Emissivity: A special case of emittance of a body that is optically smooth annd sufficiently thick to be opaque. Emissivity is a fundamental property of a material.

Emittance: The ratio of the emissive power of a given specimen to that of a blackbody radiator at the same temperature and under the same conditions. Emittance is a property of a given specimen of a material.

Normal Spectral Emittance: The ratio of the emittance of a sample at a specific wavelength and normal to the radiating surface, to that from a blackbody at the same temperature.

Total Diffuse Emittance: The ratio of the hemispheric emission by a diffuse surface to the total radiation emitted by a blackbody at the same temperature.

COMMENTS AND CONCLUSIONS

Although the presentation of spectral emittances in this report is rather wide and representative of several types of materials, there are many types of materials for which there is very little information, especially in the area of the emittance of foliage. No measurements of reflectance or emittance in the 8- to 14-micron range of materials such as asphalts and concrete have been reported in usable form. It would be useful to have 8- to 14-micron emittance measurements of materials such as concretes, asphalts, roots, grass, trees, etc., in order to make intercomparisons similar to those reported in Ref. 10 at shorter wavelengths.

In general, little work has been reported in the 8- to 14-micron region in contrast to the amount that has been reported in the shorter wavelength region. The search reported herein included investigation of over 200 articles and reports suggested by bibliographies, reference

systems, and other reports, yet it yielded only 17 reports and articles containing direct spectral emittance data extending through the 8- to 14-micron region.

General conclusions can be arrived at from analyses of information available on emittances of types of materials (Ref. 2), but no specific analysis is here presented prescribing the usefulness of the 8- to 14-micron region for target background detection.

Information on parameters and other characteristics, such as air flow, heat transfer, and cooling processes, that is needed to improve quantitative handling of target and background contrast, is limited but available. It has not, however, been collated or presented in a form useful for application to the problems of infrared detection.

Contrast occurring in some simple terrain-target situations can be inferred if models are carefully selected and if information on heat flow, sky radiation, and emittance of materials is properly applied. The difficulty of such a task lies in the development of a reasonably accurate model rather than in the lack of appropriate information.

SPECTRAL EMITTANCE OF MINERALS, ROCKS, AND TUFFS

Much information has been published on the spectral emittance of minerals, rocks, and tuffs. Absorption analyses have been made for several years to determine the absorption spectra of minerals. The information presented here is a representative sample of recent work that was rather comprehensive in scope. For further descriptions, one may either interpolate from information given here, if the composition of the material of interest is known, or refer to the works of the two major sources used in this section (Ref. 9 and 26).

Occasionally, an anomalous spectral curve was reported for one substance in a group whose members had similar emittance curves. Such obvious deviations were included here to prevent incorrect assumptions. For instance, note that the spectral emittances reported for basalt (Fig. 6) and nepheline basalt (Fig. 14) are definitely different.

Surface roughness effects are shown for dunite (Fig. 11) and quartz (Fig. 16).

A very interesting representation of the effect of particle size on emittance in the 8- to 14-micron range is shown in Fig. 22 as converted from a publication by Hovis and Callahan (Ref. 8).

Although emittances of materials presented in this section are generally quite high, significant differences exist in the spectral emittance character over the 8- to 14-micron wavelength range.

Source of the data illustrated here include absorption and reflection data. These data are shown qualitatively and the ordinate pertains only to the emittance curves.

NORMAL SPECTRAL EMITTANCE OF ANDESITE (USNM 1331)

Test Method and Data Plot

Reflection Data. Small, front-surfaced, prism-mirror system was placed in one beam of a double-beam spectrometer. Prism deflected beam out of the instrument onto the polished material surface at an angle of incidence of 30°. Radiation at the specular angle was then directed to a second mirror and reinserted into the spectrophotometer. Reproducibility on one sample was approximately 1%.

Emission Data. Single-beam Perkin-Elmer PE 112, modified for direct emission measurements, was used. Reproducibility appeared to be approximately 3%.

Absorption Data. KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Sample Temperature

Assumed to have been at or near room temperature (300°K to 330°K).

Locale

San Jose, Tamaulipas, Mexico.

Source

Ref. 26, App. A-21.

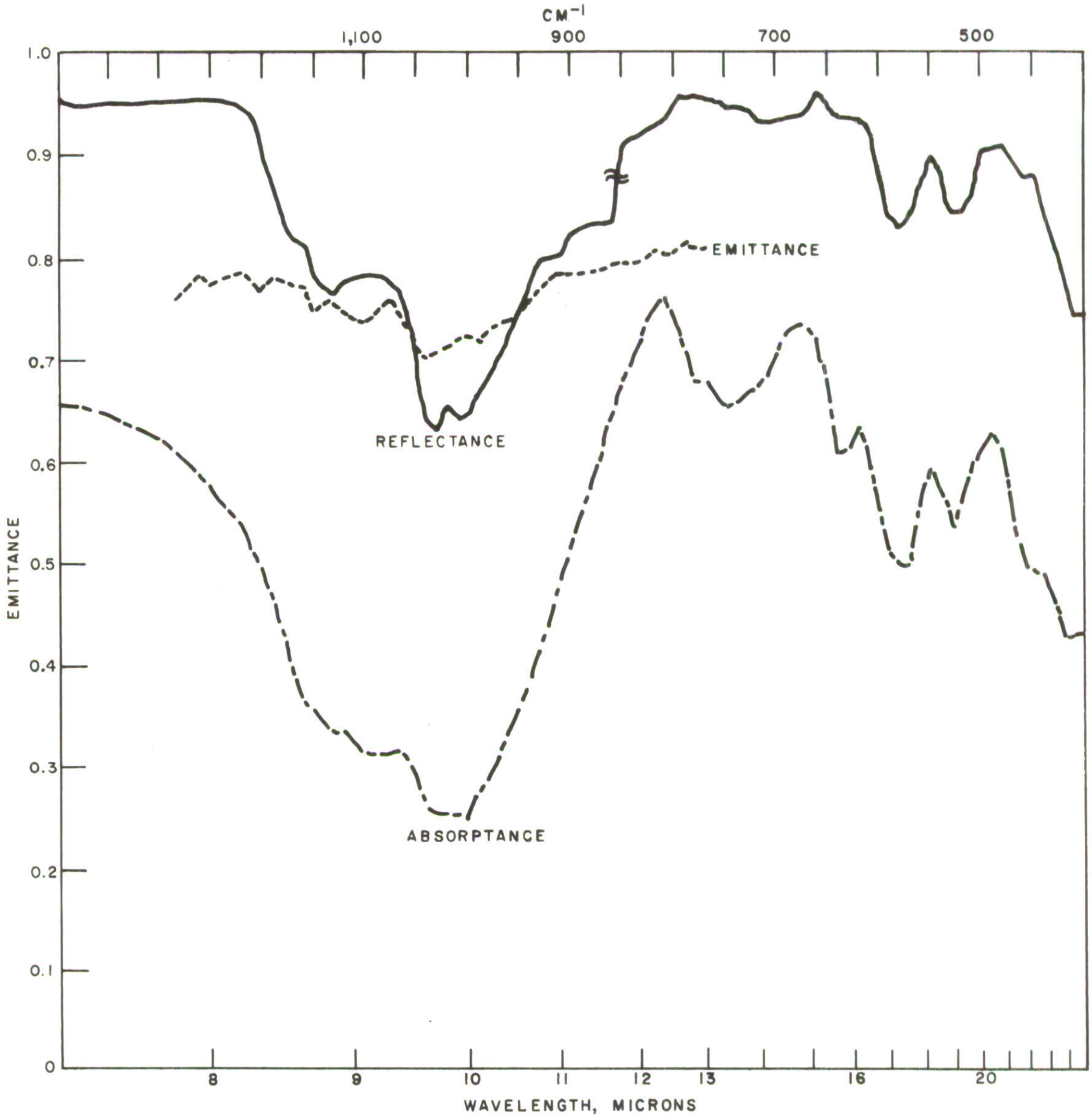

FIG. 5. Normal Spectral Emittance of Andesite (USNM 1331) With Reflection and Absorption Data. Break at 850 cm^{-1} (11.75 μ) is due to NaCl-KBr prism change during reflectance measurement.

NORMAL SPECTRAL EMITTANCE OF BASALT (USNM 102)

Test Method and Data Plot

Reflection Data. Small, front-surfaced, prism-mirror system was placed in one beam of a double-beam spectrometer. Prism deflected beam out of the instrument onto the polished material surface at an angle of incidence of 30°. Radiation at the specular angle was then directed to a second mirror and reinserted into the spectrophotometer. Reproducibility on one sample was approximately 1%.

Emission Data. Single-beam Perkin-Elmer PE 112, modified for direct emission measurements, was used. Reproducibility appeared to be approximately 3%.

Absorption Data. KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Sample Temperature

Assumed to have been at or near room temperature (300°K to 330°K).

Locale

Watchung Mountain, Orange, N.J.

Source

Ref. 26, App. A-43.

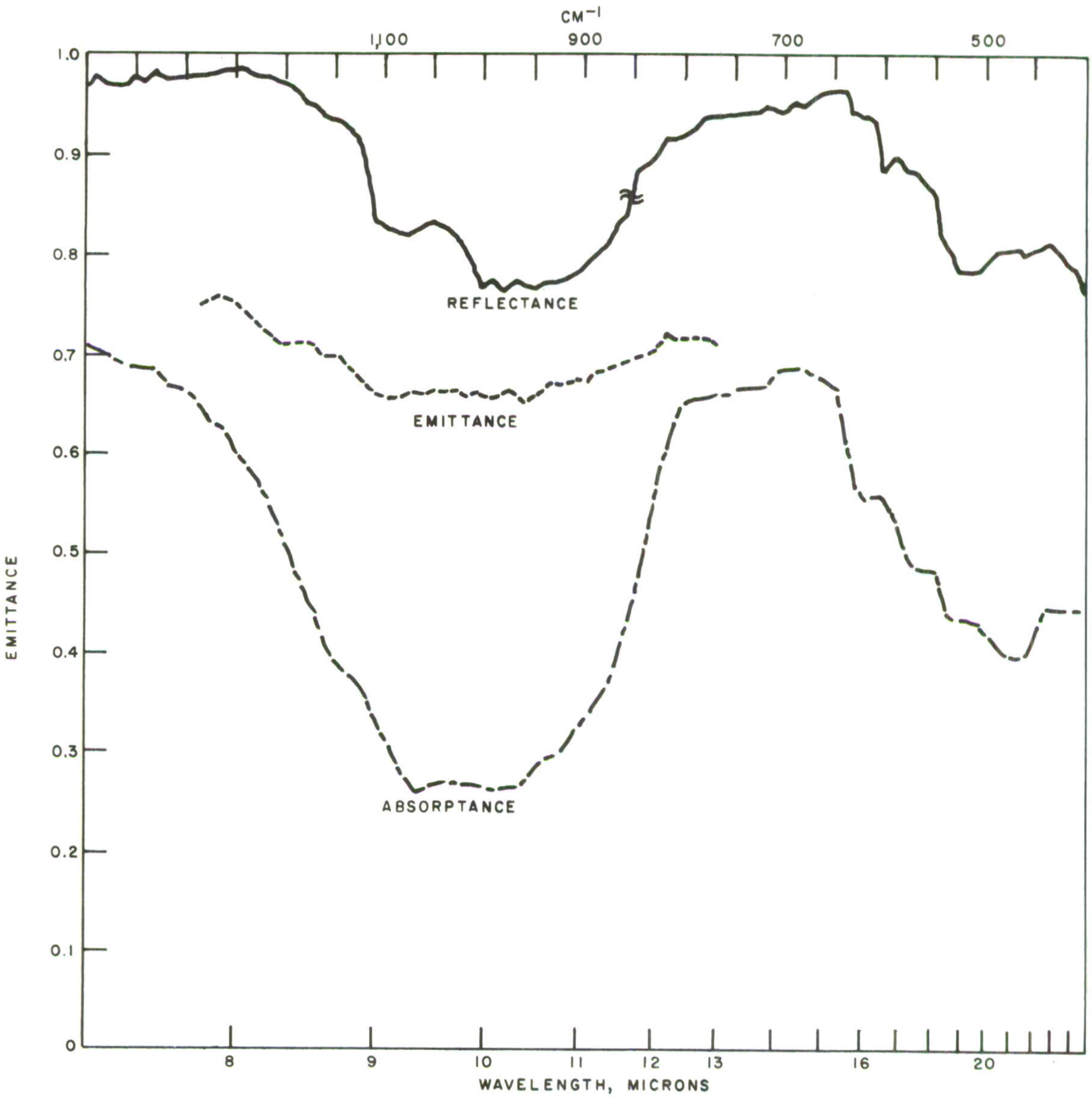

FIG. 6. Normal Spectral Emittance of Basalt (USNM 102) With Reflection and Absorption Data.

SPECTRAL EMITTANCE OF CALCIUM CARBONATE

Test Method

Over the region of 2.5 to 22 microns, reflectance measurements were made with a Cary Model 90 double-beam spectrophotometer equipped with a total reflectance attachment.

Form of Original Data Presentation

Author presented graph of reflectance versus wavelength.

Sample Temperature

At or near room temperature.

Comments

Carbonate absorption band at 11.2 microns is prominent in this and other carbonate samples.

Source

Ref. 9, Fig. 1.

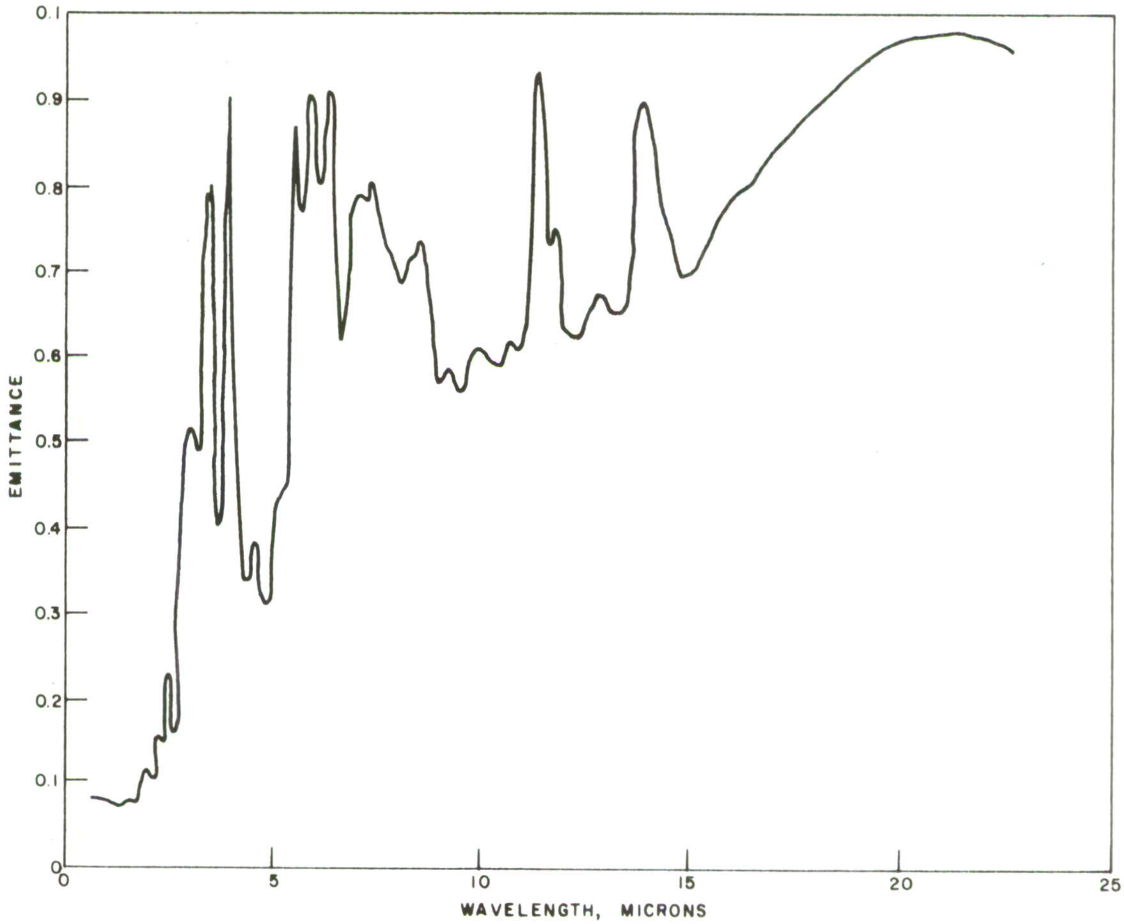

FIG. 7. Spectral Emittance of Calcium Carbonate.

NORMAL SPECTRAL EMITTANCE OF CALCITE

Test Method

Emittance measurements made using a single beam instrument.

Form of Original Data Presentation

As shown.

Surface Conditions

Sample was a cleavage plate with a highly polished surface.

Comments

The reststrahlen for the carbonate functional group occurs somewhere near 7 microns in the center of the atmospheric CO_2 absorption band. Data presented was renormalized to account for this effect.

Source

Ref. 26, p. 138.

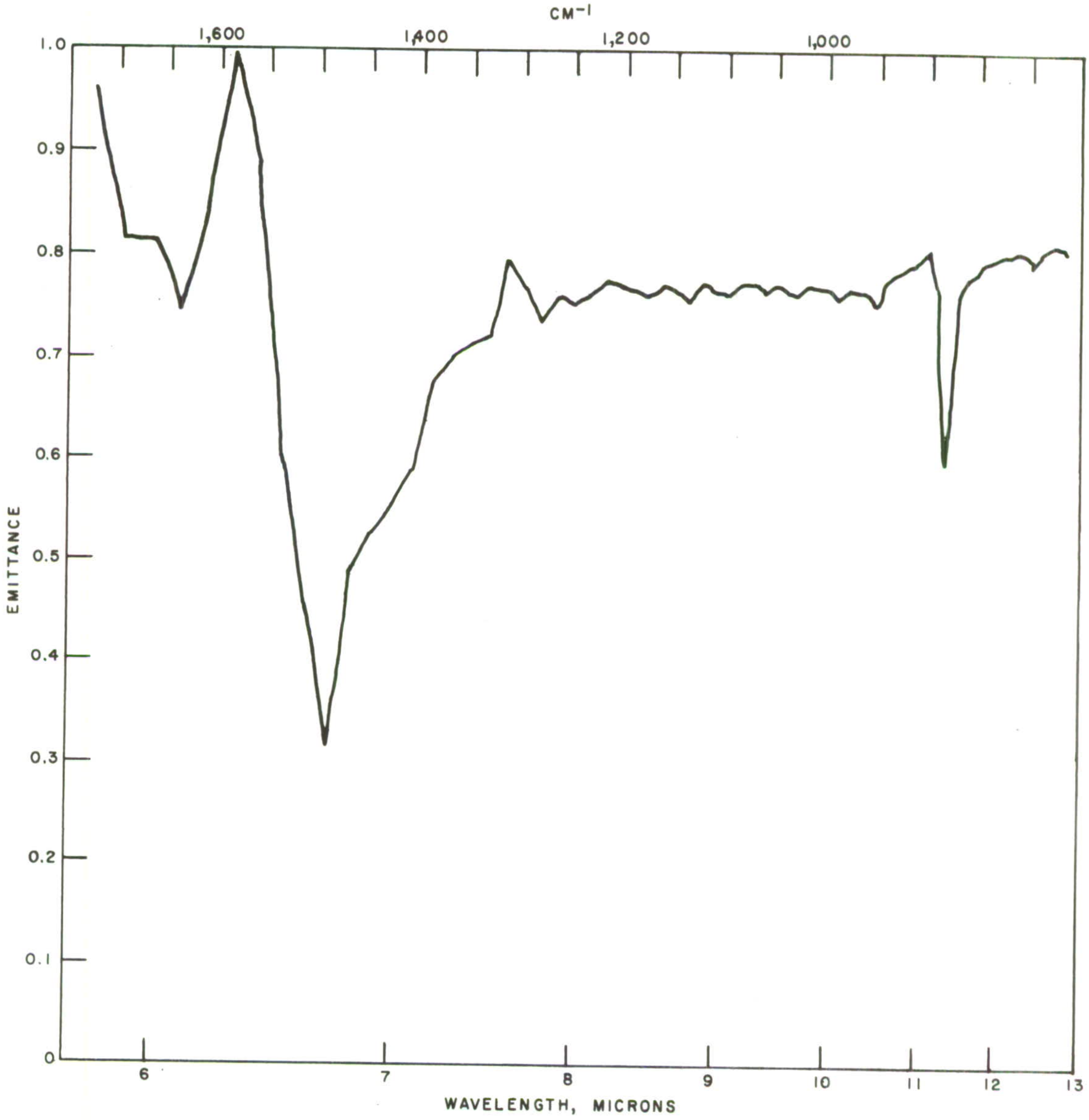

FIG. 8. Normal Spectral Emittance of Calcite.

NORMAL SPECTRAL EMITTANCE OF DACITE (USNM 82)

Test Method and Data Plot

Reflection Data. Small, front-surfaced, prism-mirror system was placed in one beam of a double-beam spectrometer. Prism deflected beam out of the instrument onto the polished material surface at an angle of incidence of 30°. Radiation at the specular angle was then directed to a second mirror and reinserted into the spectrophotometer. Reproducibility on one sample was approximately 1%.

Emission Data. Single-beam Perkin-Elmer PE 112, modified for direct emission measurements, was used. Reproducibility appeared to be approximately 3%.

Absorption Data. KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Sample Temperature

Assumed to have been at or near room temperature (300°K to 330°K).

Locale

Lassen Peak, California.

Source

Ref. 26, App. A-5.

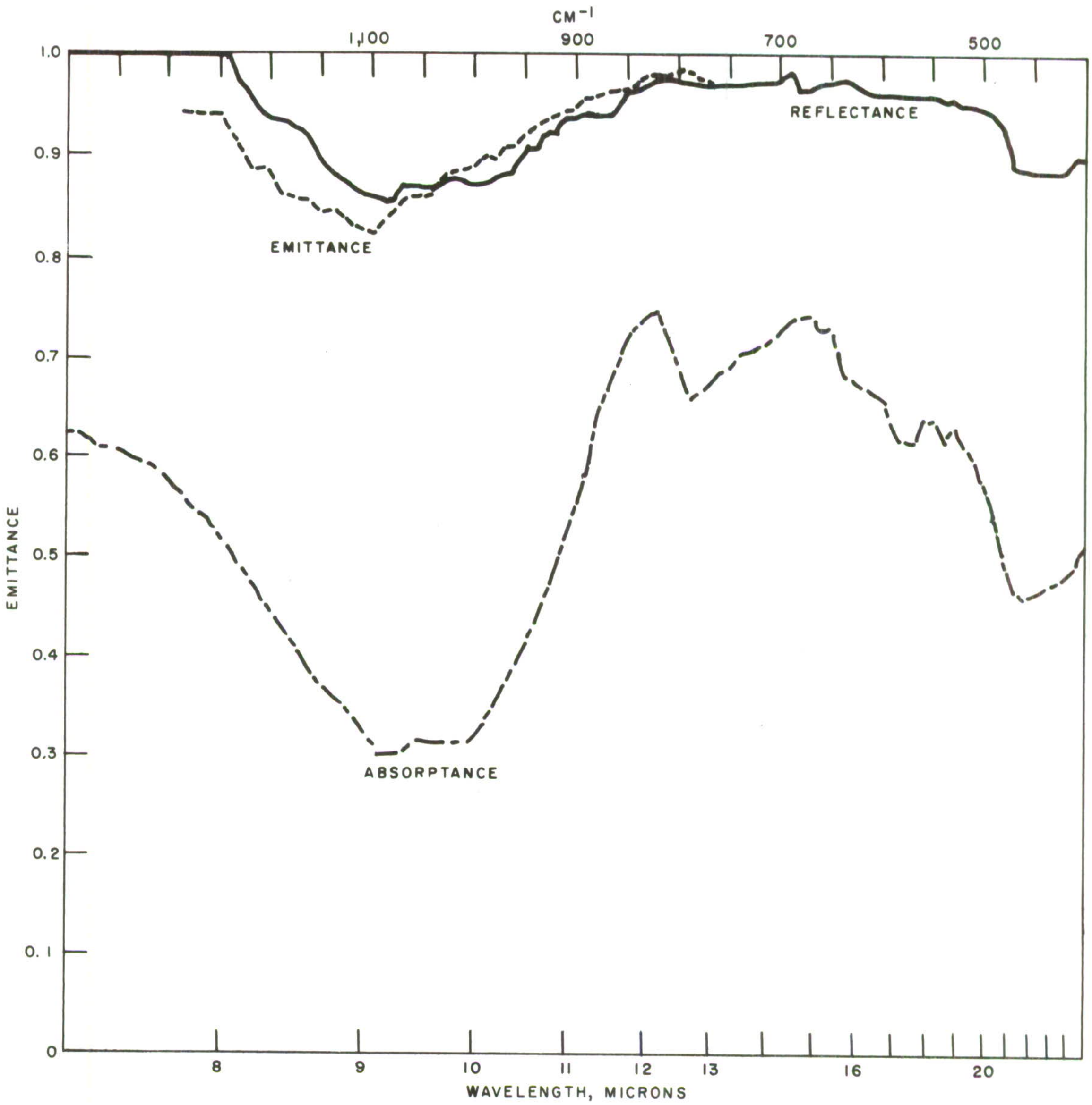

FIG. 9. Normal Spectral Emittance of Dacite (USNM 82) With Reflection and Absorption Data.

NORMAL SPECTRAL EMITTANCE OF DOLOMITE

Test Method

Single-beam Perkin-Elmer Model 112, modified for direct emission measurements. Reproducibility appeared to be about 3%.

Form of Original Data Presentation

As shown.

Sample Temperature

Between 300°K and 650°K (not precisely specified).

Surface Conditions

Weathered and roughened natural rock outcrop. The roughened surface has resulted in decrease of the minimum at 6.45 micron and 11.20 micron.

Locale

This sample was taken from the dolomite horizon at the base of the Rainier Tuff series, Rainier Mesa, Nevada Test Site.

Source

Ref. 26, p. 140.

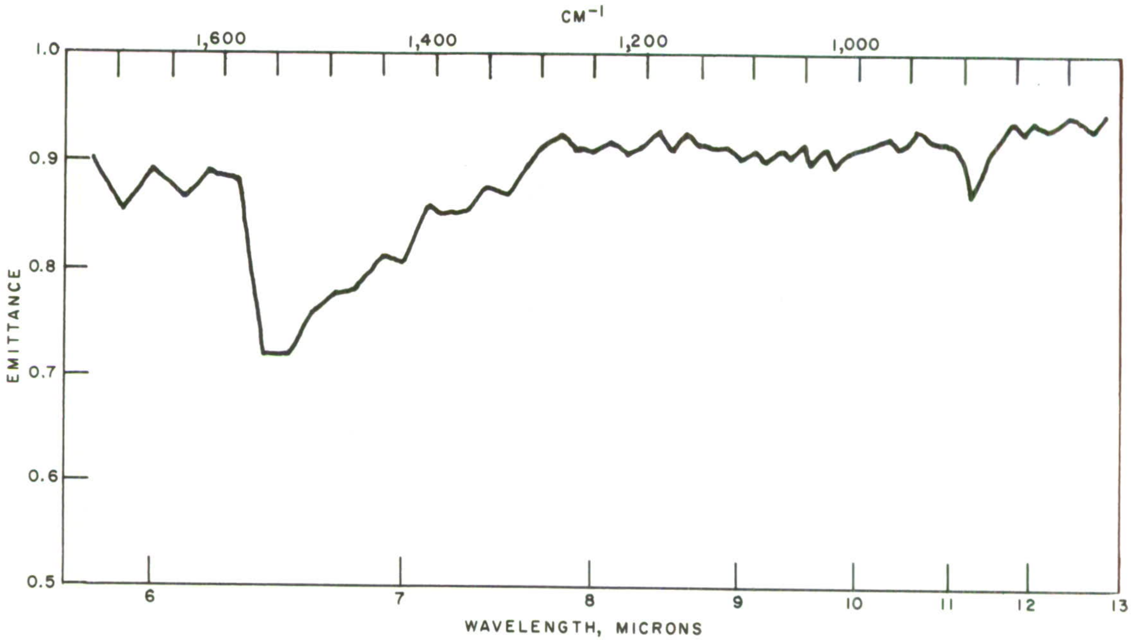

FIG. 10. Normal Spectral Emittance of Dolomite.

NORMAL SPECTRAL EMITTANCE OF DUNITE

Test Method

Not stated.

Form of Original Data Presentation

As shown.

Surface Conditions

Various degrees of surface roughness (see graph).

Source

Ref. 26, p. 100.

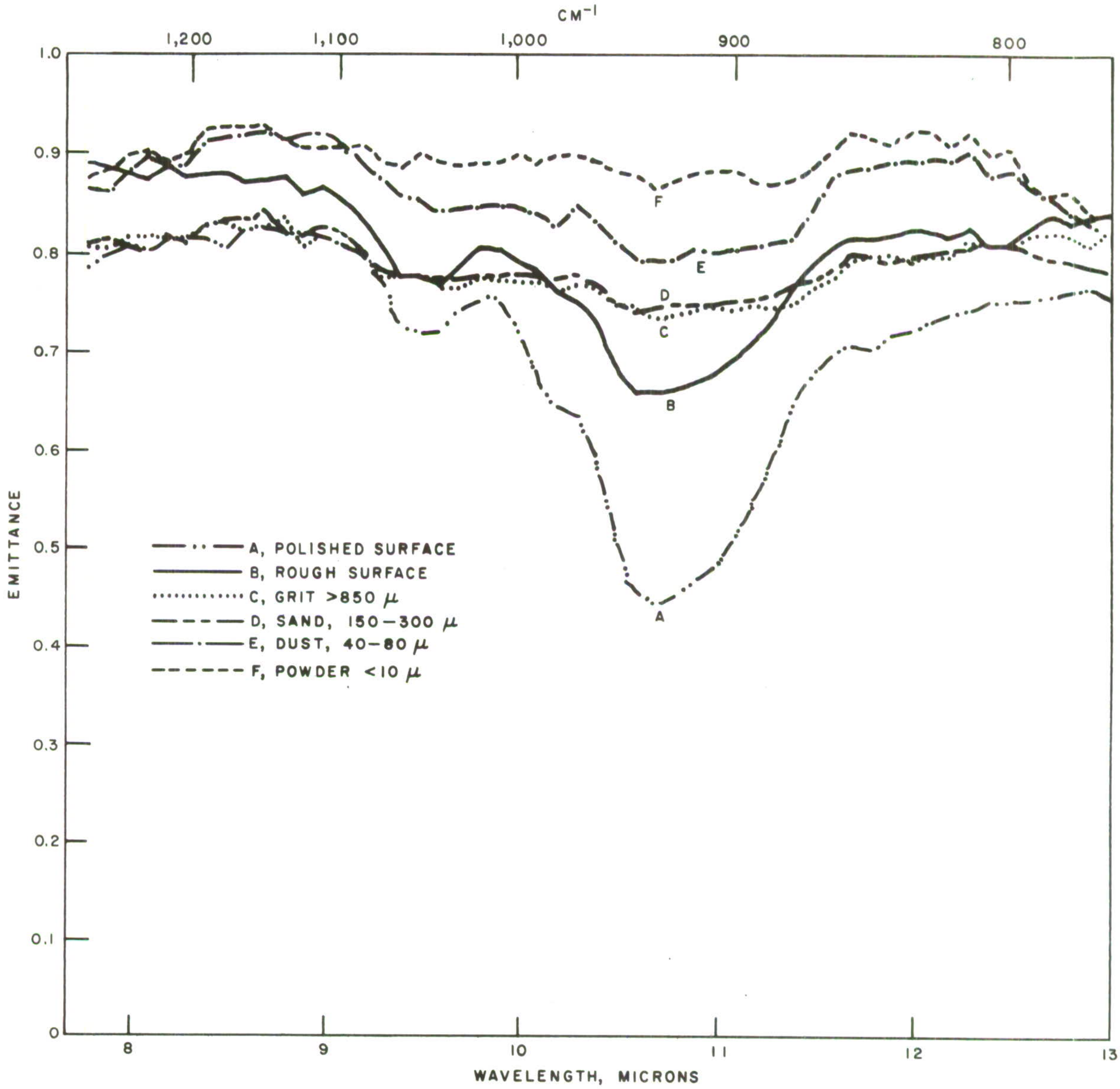

FIG. 11. Normal Spectral Emittance of Dunite (Various Surface Roughnesses).

NORMAL SPECTRAL EMITTANCE OF GRANITE (USNM 158)

Test Method and Data Plot

Reflection Data. Small, front-surfaced, prism-mirror system was placed in one beam of a double-beam spectrometer. Prism deflected beam out of the instrument onto the polished material surface at an angle of incidence of 30°. Radiation at the specular angle was then directed to a second mirror and reinserted into the spectrophotometer. Reproducibility on one sample was approximately 1%.

Emission Data. Single-beam Perkin-Elmer PE 112, modified for direct emission measurements, was used. Reproducibility appeared to be approximately 3%.

Absorption Data. KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Sample Temperature

Assumed to have been at or near room temperature (300°K to 330°K).

Locale

Ockerthal, Hartz Mts.

Source

Ref. 26, App. A-7.

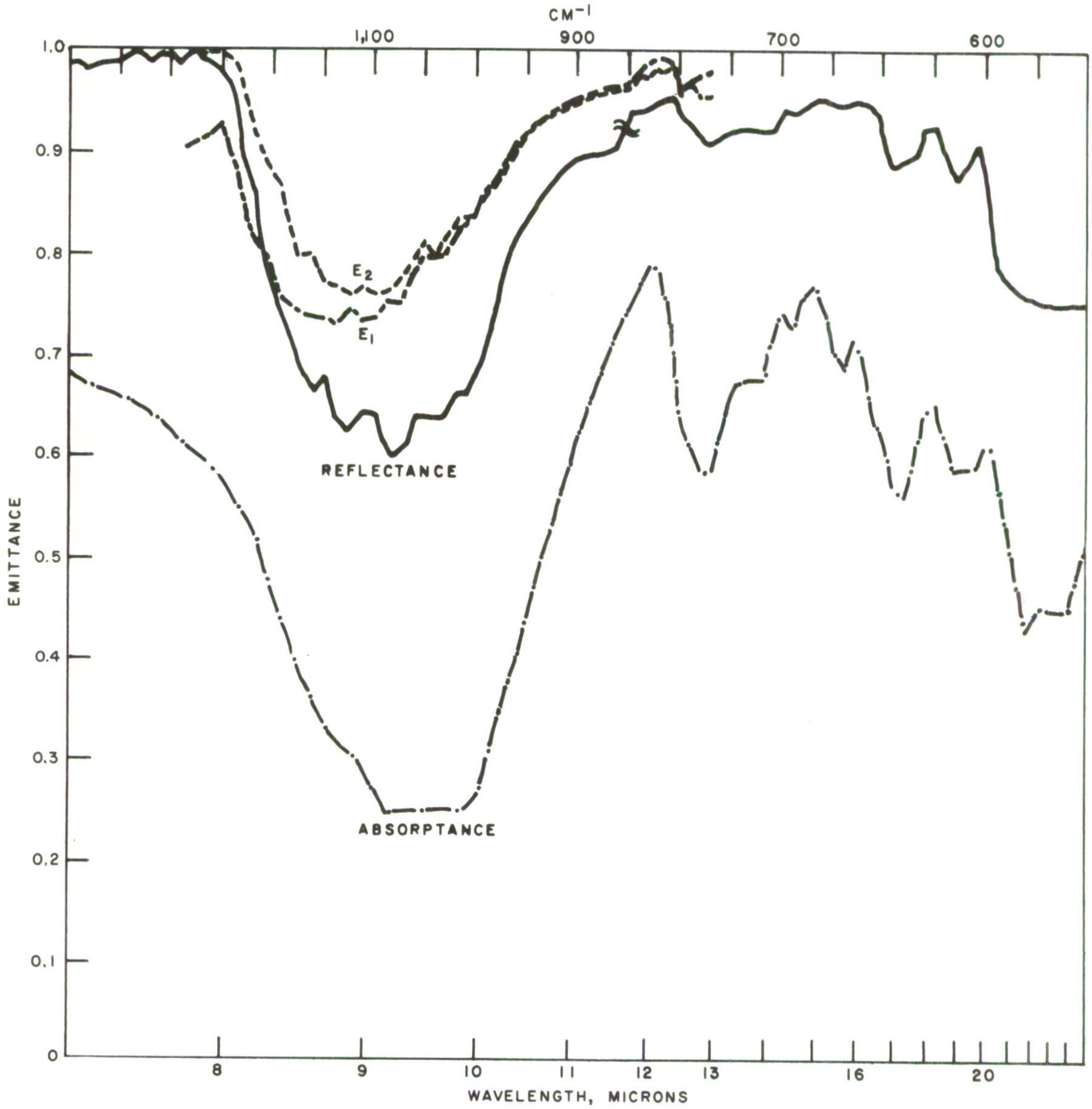

FIG. 12. Normal Spectral Emittance of Granite (USNM 158) With Reflection and Absorption Data. Emittance spectra (E_1 and E_2) show slightly different minima.

NORMAL SPECTRAL EMITTANCE OF LIMBURGITE (USNM 296)

Test Method and Data Plot

Reflection Data. Small, front-surfaced, prism-mirror system was placed in one beam of a double-beam spectrometer. Prism deflected beam out of the instrument onto the polished material surface at an angle of incidence of 30°. Radiation at the specular angle was then directed to a second mirror and reinserted into the spectrophotometer. Reproducibility on one sample was approximately 1%.

Emission Data. Single-beam Perkin-Elmer PE 112, modified for direct emission measurements, was used. Reproducibility appeared to be approximately 3%.

Absorption Data. KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Sample Temperature

Assumed to have been at or near room temperature (300°K to 330°K).

Locale

Dewitt, near Syracuse, N.Y.

Source

Ref. 26, App. A-59.

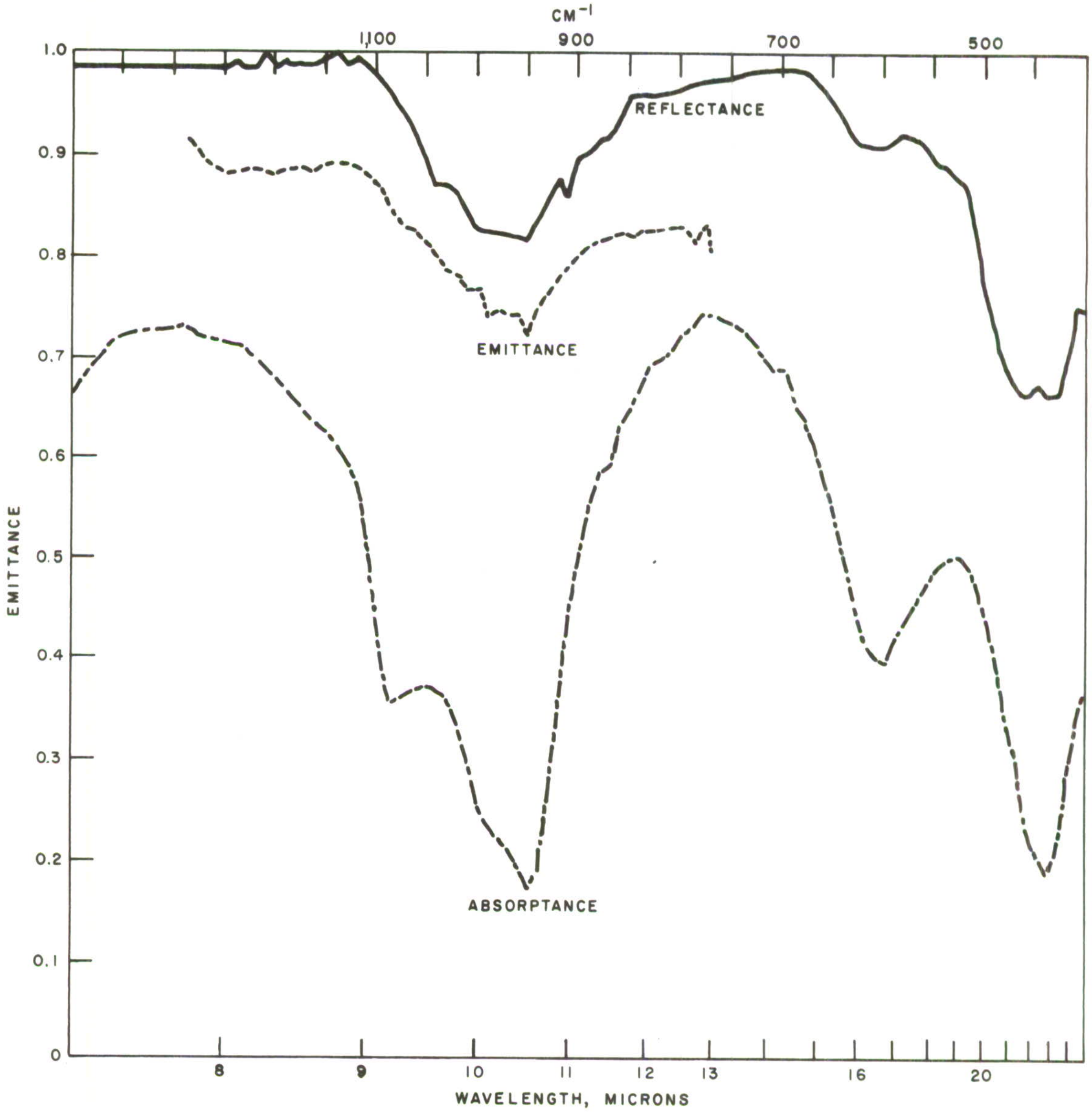

FIG. 13. Normal Spectral Emittance of Limburgite (USNM 296) With Reflection and Absorption Data.

NEAR-NORMAL SPECTRAL EMITTANCE OF NEPHELINE BASALT (USNM 1065)

Test Method and Data Plot

Reflection Data. Small, front-surfaced, prism-mirror system was placed in one beam of a double-beam spectrometer. Prism deflected beam out of the instrument onto the polished material surface at an angle of incidence of 30°. Radiation at the specular angle was then directed to a second mirror and reinserted into the spectrophotometer. Reproducibility on one sample was approximately 1%.

Emission Data. Single-beam Perkin-Elmer PE 112, modified for direct emission measurements, was used. Reproducibility appeared to be approximately 3%.

Absorption Data. KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Sample Temperature

Assumed to have been at or near room temperature (300°K to 330°K).

Locale

Tom Nunn's Hill, S. S. W. of Uvalde, Uvalde quadrangle, Texas.

Source

Ref. 27, App. A-55.

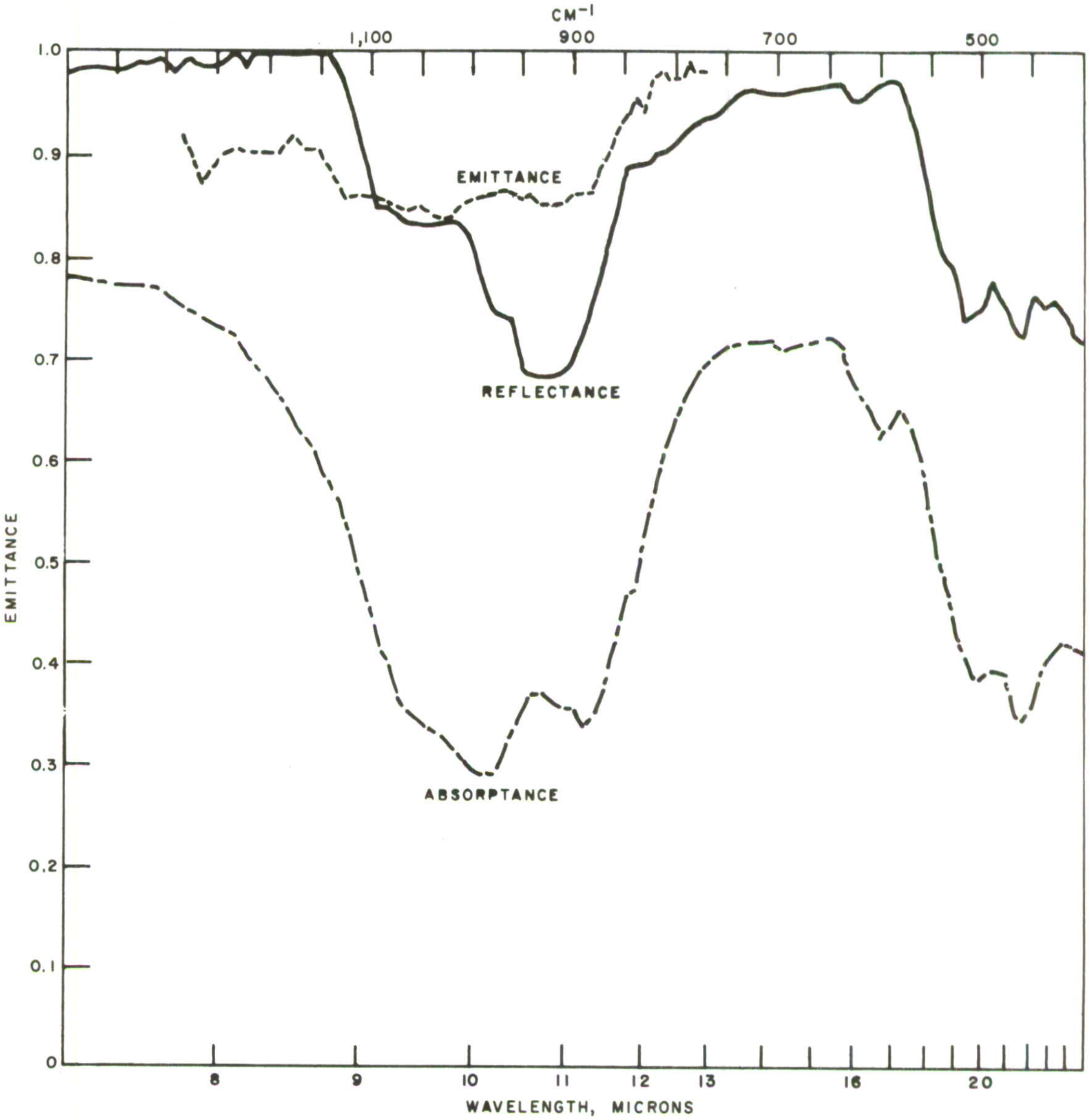

FIG. 14. Near-Normal Spectral Emittance of Nepheline Basalt (USNM 1065) With Reflection and Absorption Data.

NORMAL SPECTRAL REFLECTANCE OF OPAL (USNM 1391)

Test Method and Data Plot

Reflection Data. Small, front-surfaced, prism-mirror system was placed in one beam of a double-beam spectrometer. Prism deflected beam out of the instrument onto the polished material surface at an angle of incidence of 30°. Radiation at the specular angle was then directed to a second mirror and reinserted into the spectrophotometer. Reproducibility on one sample was approximately 1%.

Emission Data. Single-beam Perkin-Elmer PE 112, modified for direct emission measurements, was used. Reproducibility appeared to be approximately 3%.

Absorption Data. KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Sample Temperature

Assumed to have been at or near room temperature (300°K to 330°K).

Locale

Buffalo Peaks, Park Co., Colorado.

Source

Ref. 26, App. A-3.

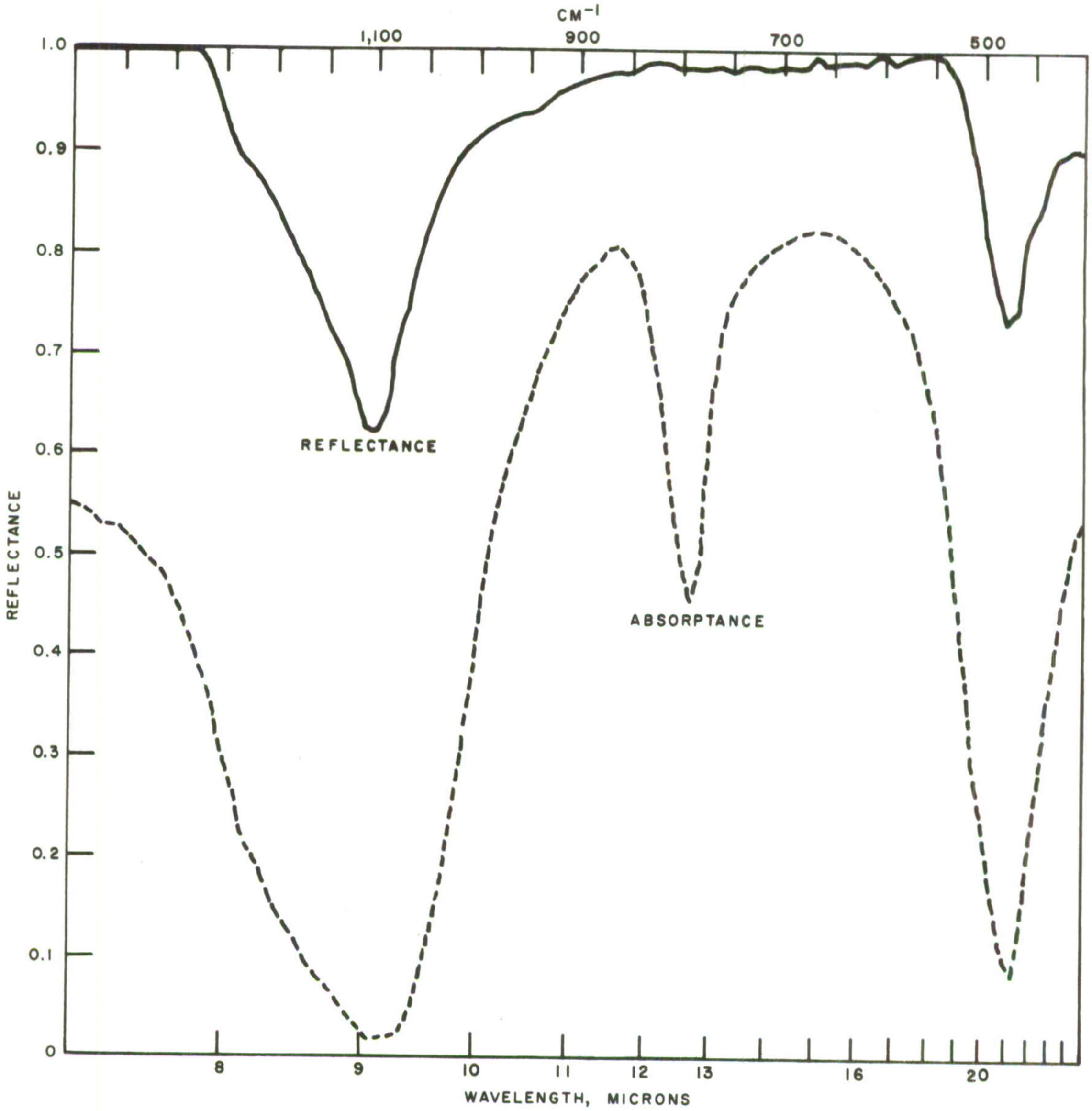

FIG. 15. Normal Spectral Reflectance of Opal (USNM 1391) With Absorption Data. Emittance spectrum not prepared, reflectance from polished surface normalized and shown as $(1 - \rho)$, absorption spectrum from a KBr pellet preparation shown as an unnormalized plot of transmission (%T). Note 12.65 μ minimum does not appear on reflection spectrum, while fundamentals at 9.09 and 21.3 μ show clearly.

NORMAL SPECTRAL EMITTANCE OF QUARTZ

Test Method and Data Plot

For the emission measurements, a single-beam Perkin-Elmer Model 112 spectrometer, modified for direct emission measurements, was used. Reproducibility for a given sample appeared to be approximately 3%. For the absorption data, measurements were taken with a KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Surface Conditions

Surface for plot E_2 was produced by sandblasting the smooth surface that yielded the data for plot E_3, a polished sample.

Comments

The low emittance of the polished quartz plate at 9.0 microns must be due to an absorption length that is short compared to the wavelength.

Source

Ref. 26, p. 113.

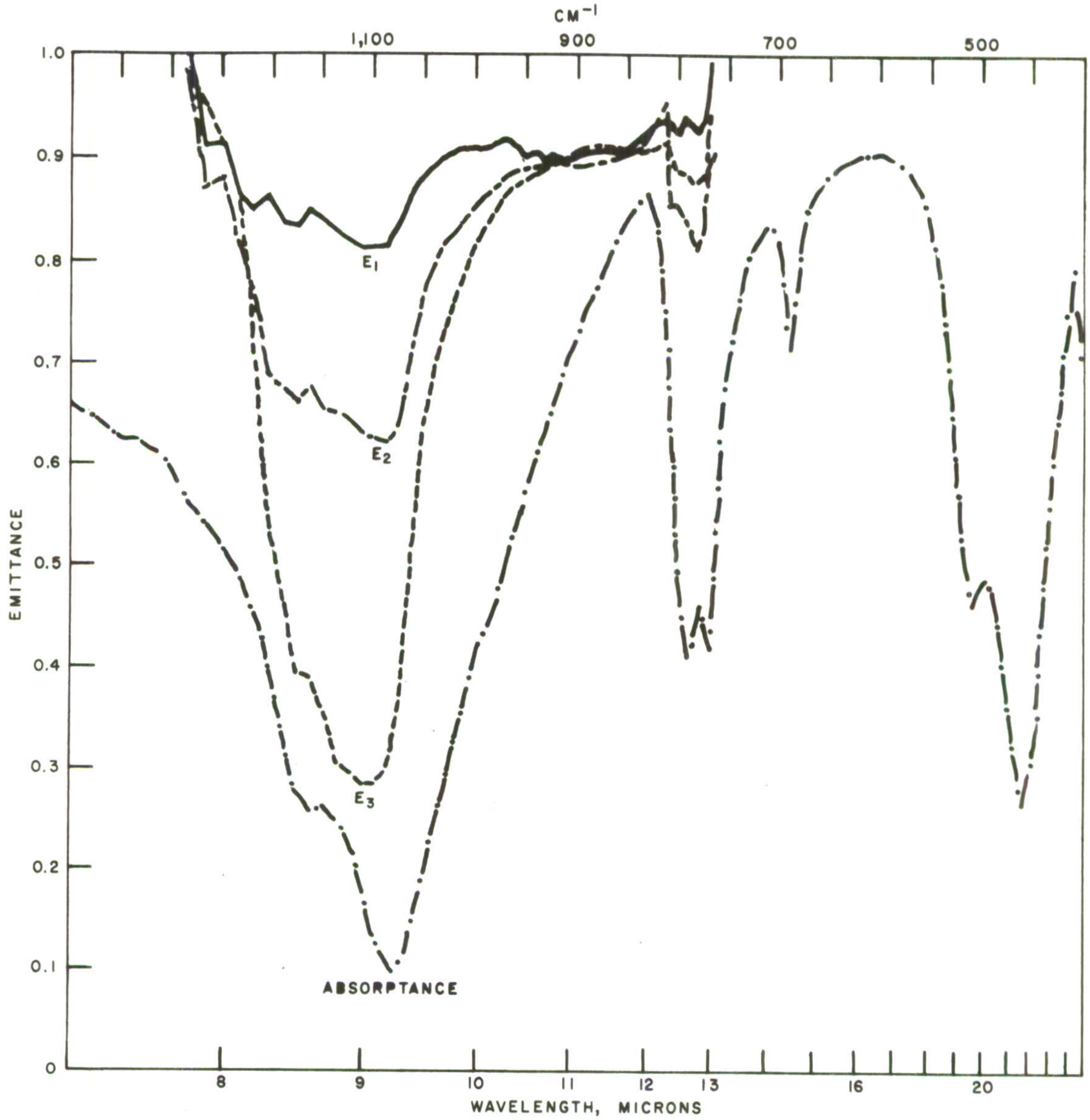

FIG. 16. Normal Spectral Emittance of Quartz. The emittance of a polished X-plate (E_3) is shown contrasted with that of the roughened surface (E_2). Also plotted on the diagram are the emittance spectrum of 25 to 45 μ quartz powder (E_1) and the absorption spectrum of quartz powder.

SPECTRAL EMITTANCE OF RED SANDSTONE

Test Method

Over the range of 2.5 to 22 microns, total reflectance measurements were measured on a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Authors presented graph of reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Solid surfaces not polished but used in a freshly fractured state. This was done to approximate the natural state of occurrence of the materials as much as possible.

Comments

In this study, varying particle size introduced reduced spectral contrast and, in some cases, a new feature that could lead to confusion in identification unless particle size is known.

Source

Ref. 8, Fig. 8.

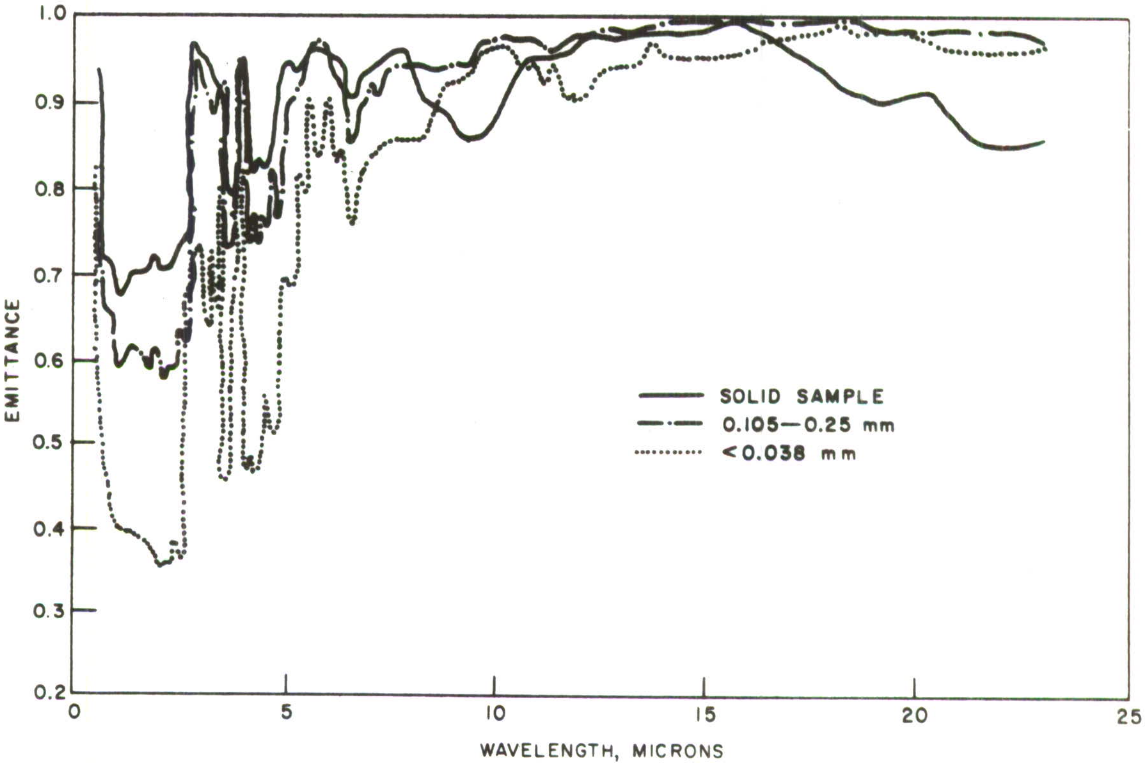

FIG. 17. Spectral Emittance of Red Sandstone.

NORMAL SPECTRAL EMITTANCE OF SERPENTINE (USNM 145)

Test Method and Data Plot

Reflection Data. Small, front-surfaced, prism-mirror system was placed in one beam of a double-beam spectrometer. Prism deflected beam out of the instrument onto the polished material surface at an angle of incidence of 30°. Radiation at the specular angle was then directed to a second mirror and reinserted into the spectrophotometer. Reproducibility on one sample was approximately 1%.

Emission Data. Single-beam Perkin-Elmer Model 112 spectrometer, modified for direct emission measurements, was used. Reproducibility appeared to be approximately 3%.

Absorption Data. KBr pellet run in the standard manner.

Form of Original Data Presentation

As shown.

Sample Temperature

Assumed to have been at or near room temperature (300°K to 330°K).

Comments

Minimum at 610 cm^{-1} (16.5 micron) is characteristic of Mg-silicate (serpentine).

Locale

Greenville, Plumas County, California.

Source

Ref. 26, App. A-57.

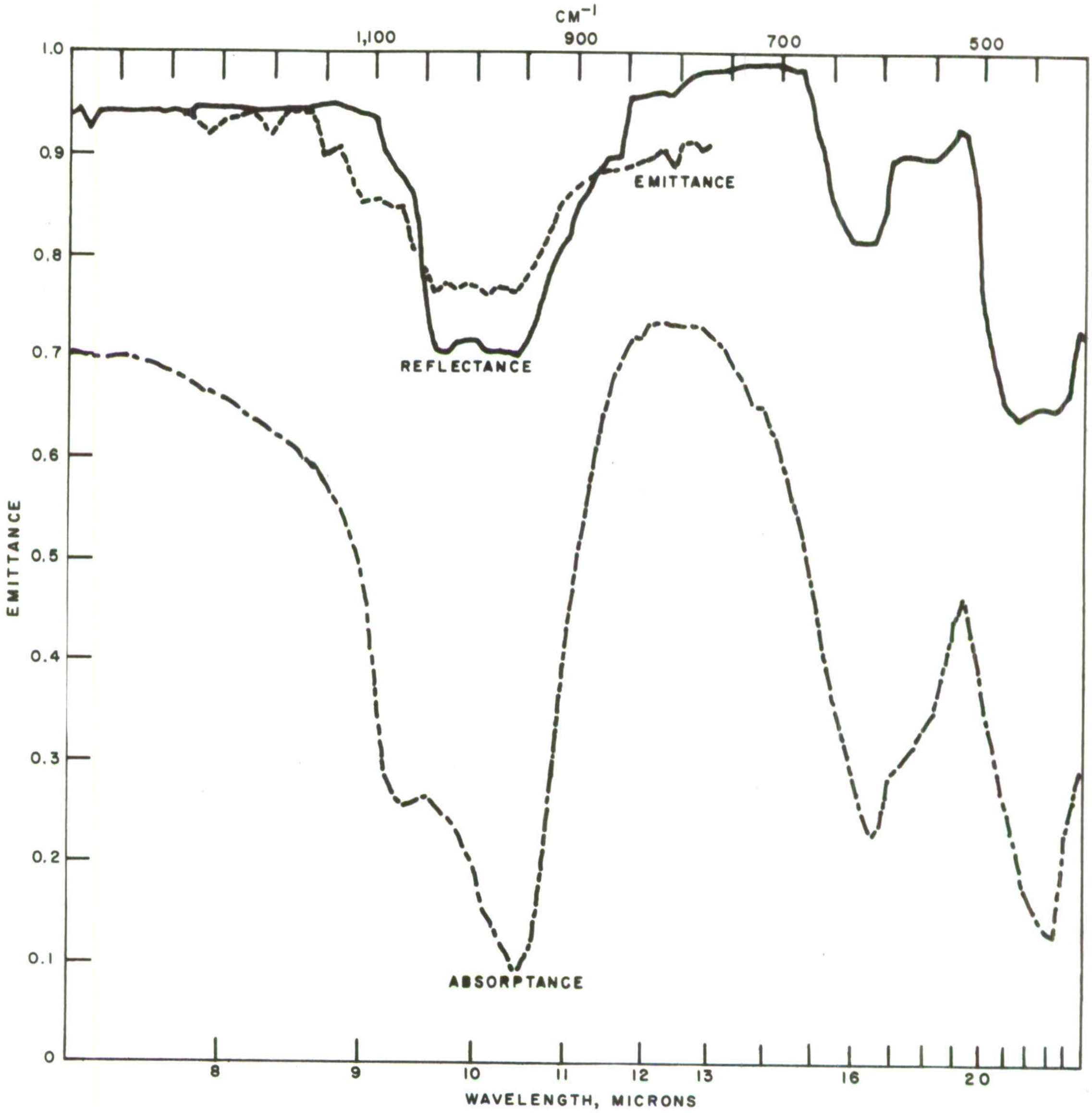

FIG. 18. Normal Spectral Emittance of Serpentine (USNM 145) With Reflection and Absorption Data.

SPECTRAL EMITTANCE OF TEKTITE

Test Method

Over the range of 2.5 to 22 microns, total reflectance measurements were measured on a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Authors presented graph of reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Solid surfaces not polished but used in a freshly fractured state. This was done to approximate the natural state of occurrence of the materials as much as possible.

Comments

In this study, varying particle size introduced reduced spectral contrast and, in some cases, a new feature that could lead to confusion in identification unless particle size is known.

Locale

Southeast Asia.

Source

Ref. 8, Fig. 5.

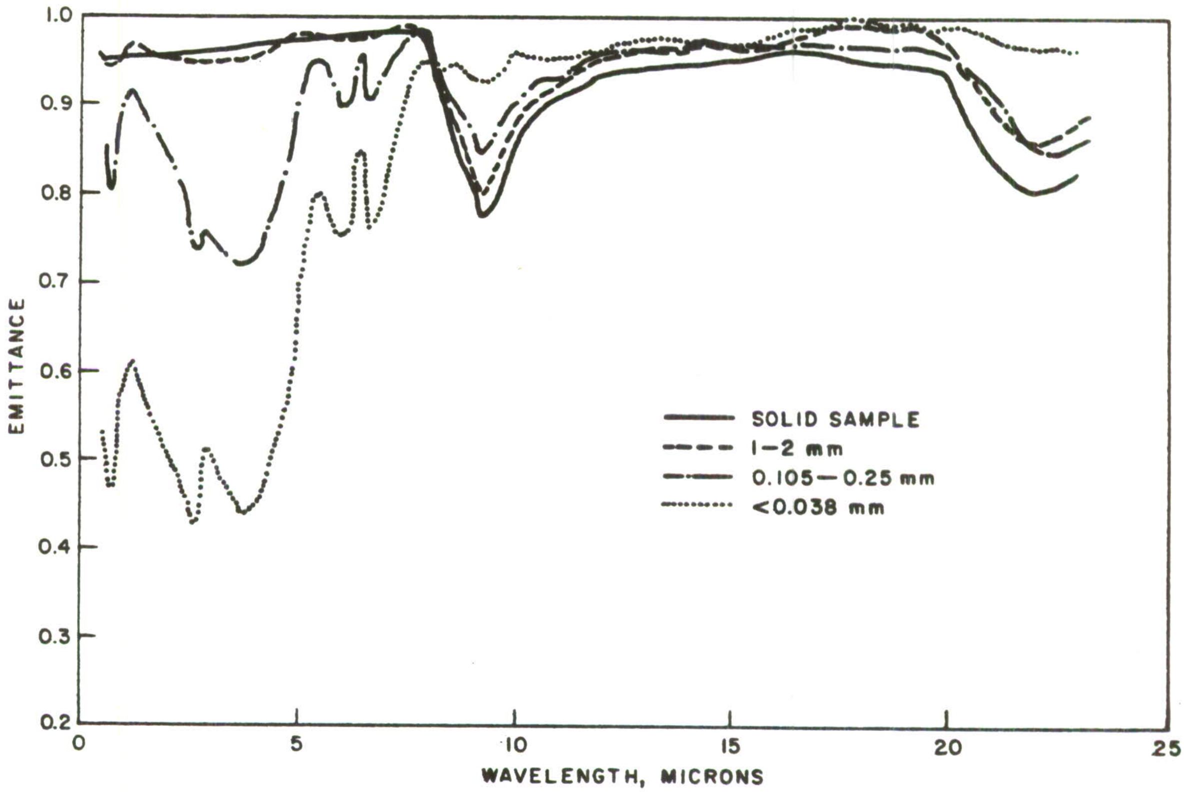

FIG. 19. Spectral Emittance of Tektite.

SPECTRAL EMITTANCE OF YELLOWSTONE TUFF NO. 6

Test Method

Over the range of 2.5 to 22 microns, total reflectance measurements were measured on a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Authors presented graph of reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Solid surfaces not polished but used in a freshly fractured state. This was done to approximate the natural state of occurrence of the materials as much as possible.

Comments

In this study, varying particle size introduced reduced spectral contrast and, in some cases, a new feature that could lead to confusion in identification unless particle size is known.

Source

Ref. 8, Fig. 7.

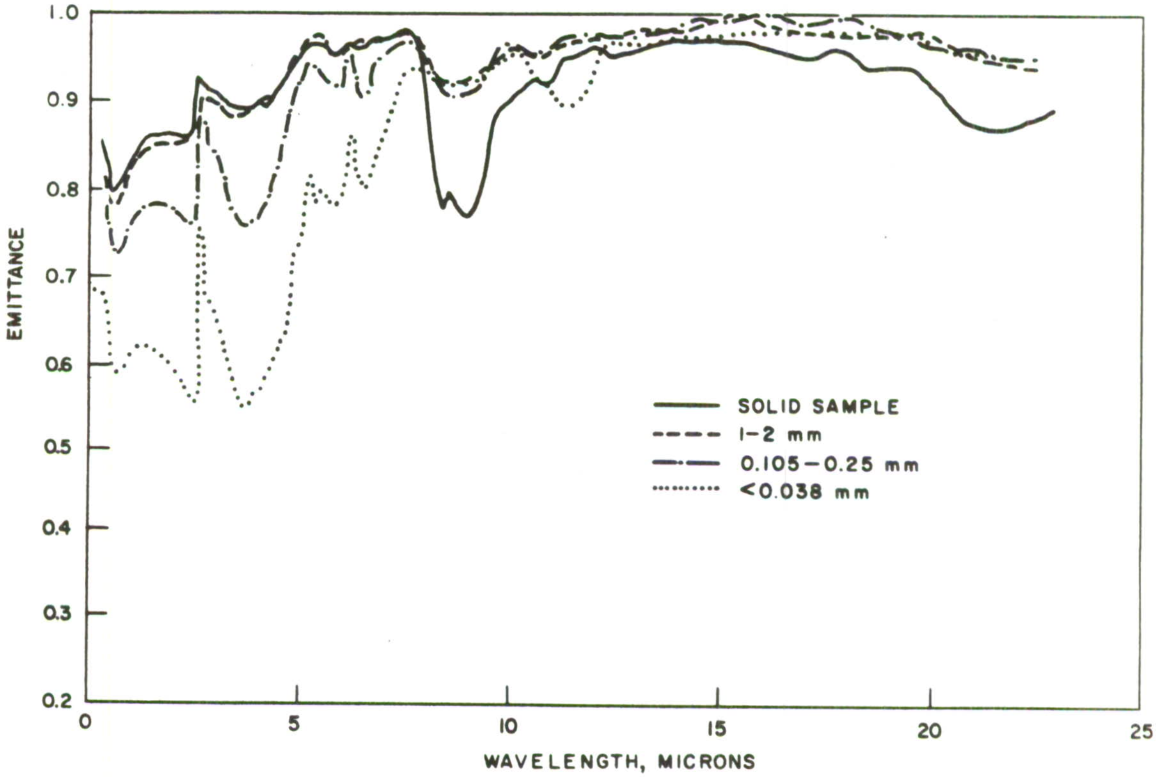

FIG. 20. Spectral Emittance of Yellowstone Tuff No. 6.

SPECTRAL EMITTANCE OF YELLOWSTONE TUFF NO. 62-13

Test Method

Over the range of 2.5 to 22 microns, total reflectance measurements were measured on a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Authors presented graph of reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Solid surfaces not polished but used in a freshly fractured state. This was done to approximate the natural state of occurrence of the materials as much as possible.

Comments

In this study, varying particle size introduced reduced spectral contrast and, in some cases, a new feature that could lead to confusion in identification unless particle size is known.

Source

Ref. 8, Fig. 6.

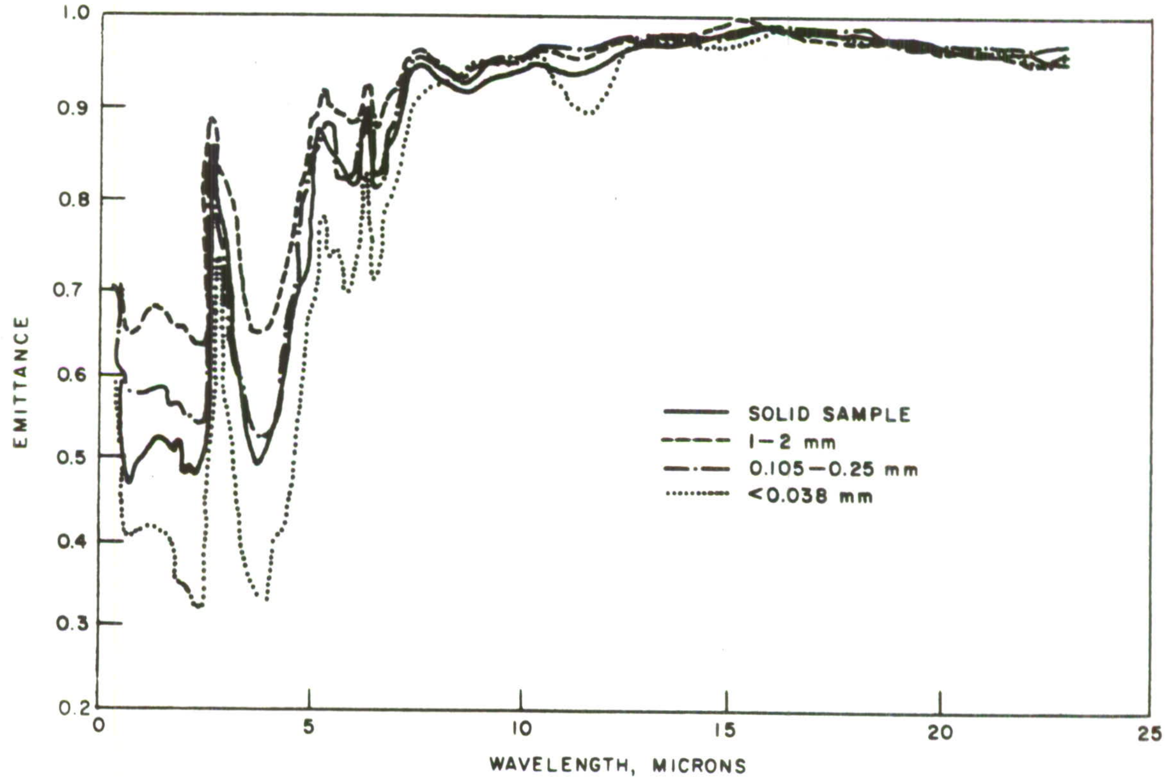

FIG. 21. Spectral Emittance of Yellowstone Tuff No. 62-13.

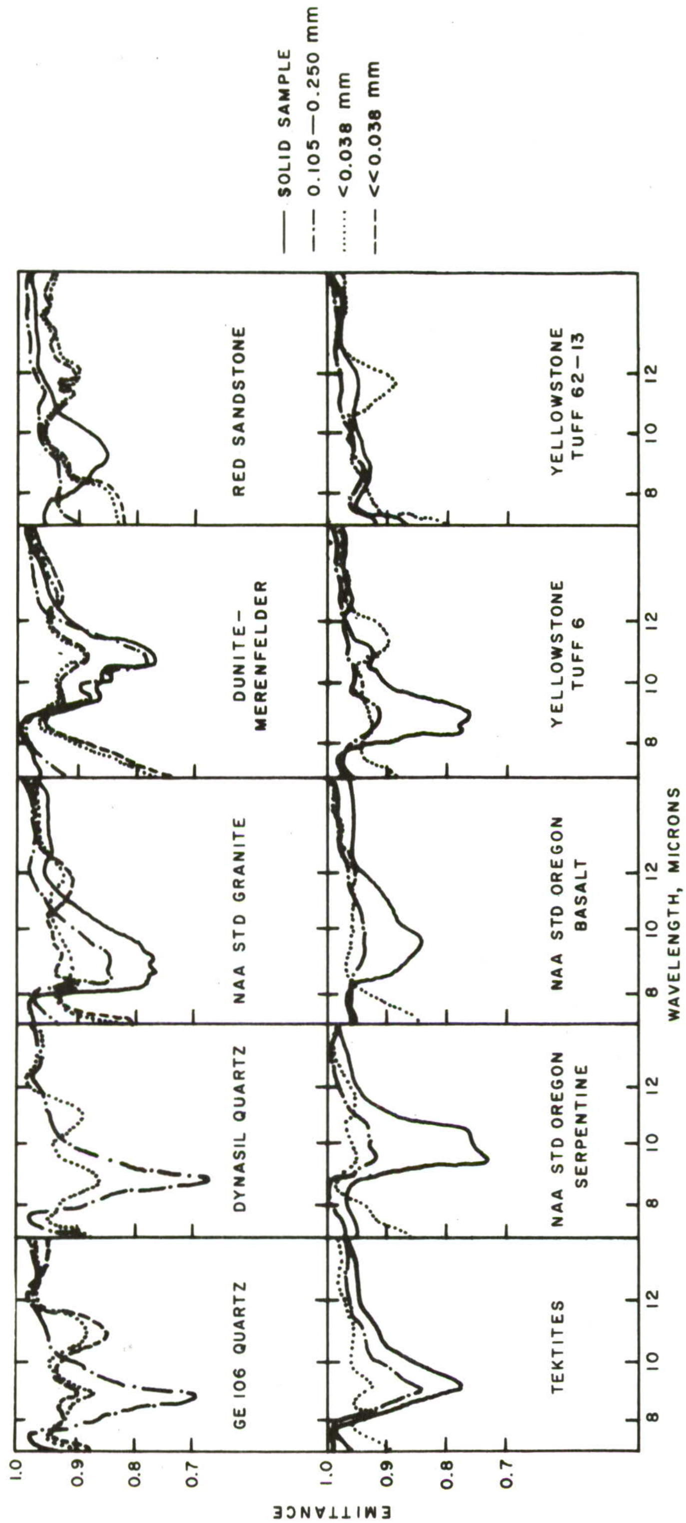

FIG. 22. Spectral Emittance of Rocks and Tuffs Showing Effect of Particle Size.

SPECTRAL EMITTANCE OF SANDS, DUST COATINGS, AND SOILS

SANDS (Fig. 23 to 25)

The three sands presented show slightly different character and overall level of emittance, but the reststrahlen near 9 microns is evident in each. The samples do not include a large number of specimens from many areas and, since minerals peculiar to a particular region may introduce significant characteristics into the spectral emittance curves, more widely chosen samples are necessary for a truly comprehensive view.

All information presented is from the same two authors, Lyon and Hovis.

DUST COATINGS (Fig. 26 to 31)

Dust coverings can change the emittance of a surface to a great extent. Note the dip in the 8- to 14-micron region of the emittance curve of Monterey sand on sodium silicate (Fig. 31) which does not occur as markedly in the sample of "light" dirt dusted on the same background material (Fig. 30). The sand reststrahlen is also evident in the spectrum of sand dusted upon black paint (Fig. 28).

All of these dusted coatings were reported by Gier and Dunkle. Here, as in the section above, the selection is small and a classification of spectral emittance of many types of dust coatings is desirable, though it appears that such information does not exist at present.

SOILS (Fig. 32 to 34)

The small sample of graphs presented here, all by the same investigator, show uniform character and high level in the 8- to 14-micron region. However, the material presented for soils represents the very limited number of samples that have been investigated in the 8- to 14-micron range (except see Ref. 28).

NORMAL SPECTRAL EMITTANCE OF ANHYDRITE AND QUARTZ SANDS

Sample Characteristics

Anhydrite sand had an average grain size of 150 to 300 microns. Quartz sand was of "small particle size".

Form of Original Data Presentation

As shown.

Comments

Note the emission minima are displaced from that of the anhydrite (8.60 micron) to that of the quartz (9.10 micron), a distance of 0.5 micron.

Source

Ref. 26, p. 141.

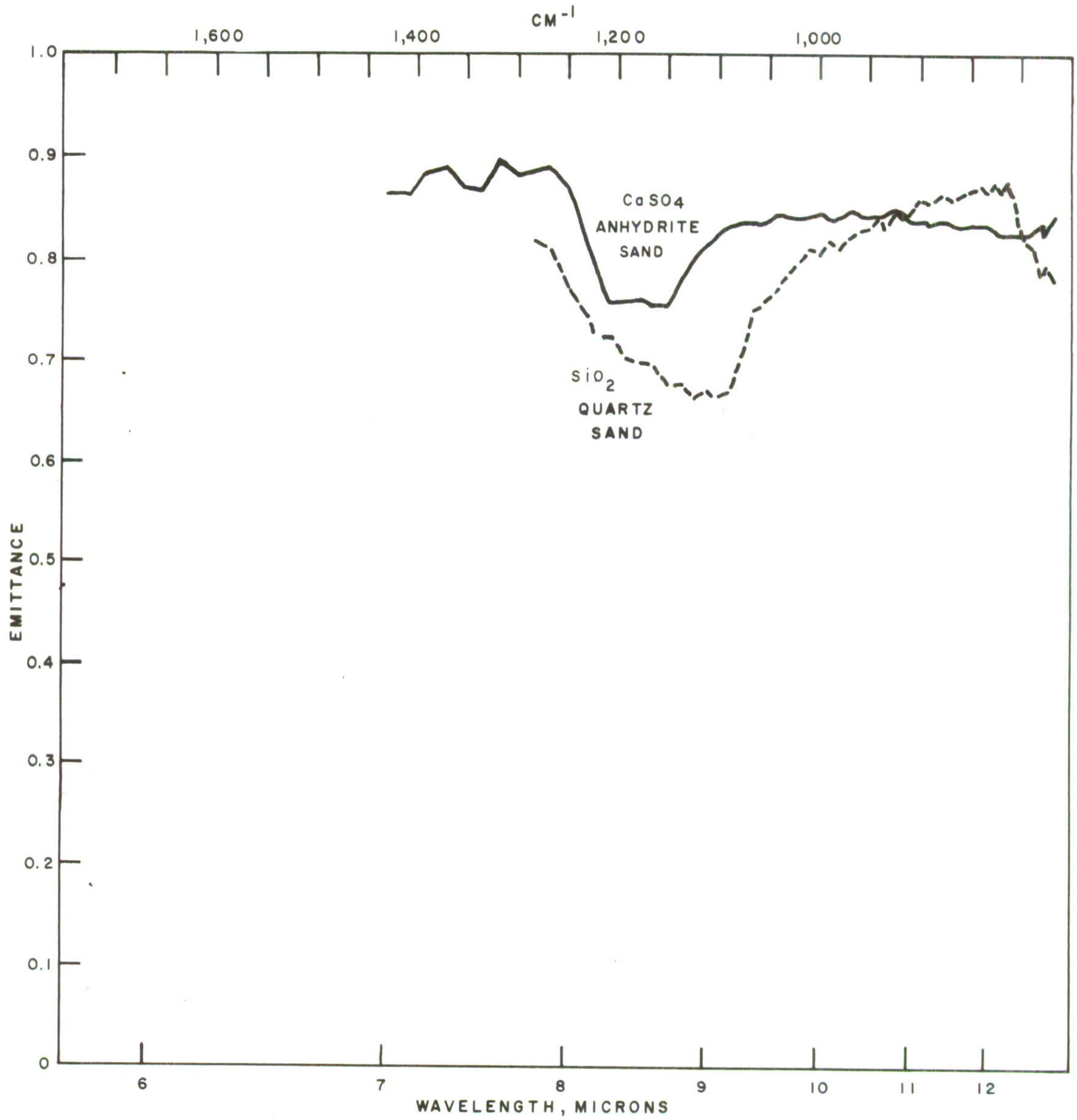

FIG. 23. Normal Spectral Emittance of Anhydrite and Quartz Sands.

SPECTRAL EMITTANCE OF BEACH SAND

Test Method

Over the range of 2.5 to 22 microns, reflectance measurements were made with a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Author presented graph of reflectance versus wavelength.

Sample Temperature

At or near room temperature.

Comments

Sample had similar spectral characteristics to another sample of beach sand from Atlantic City, New Jersey, but the principle minima in the curves of that sample were about 10% deeper. Intensity of residual ray features such as appear in the 8- to 12-micron region is a function of particle size.

Locale

Daytona Beach, Florida.

Source

Ref. 9, Fig. 7.

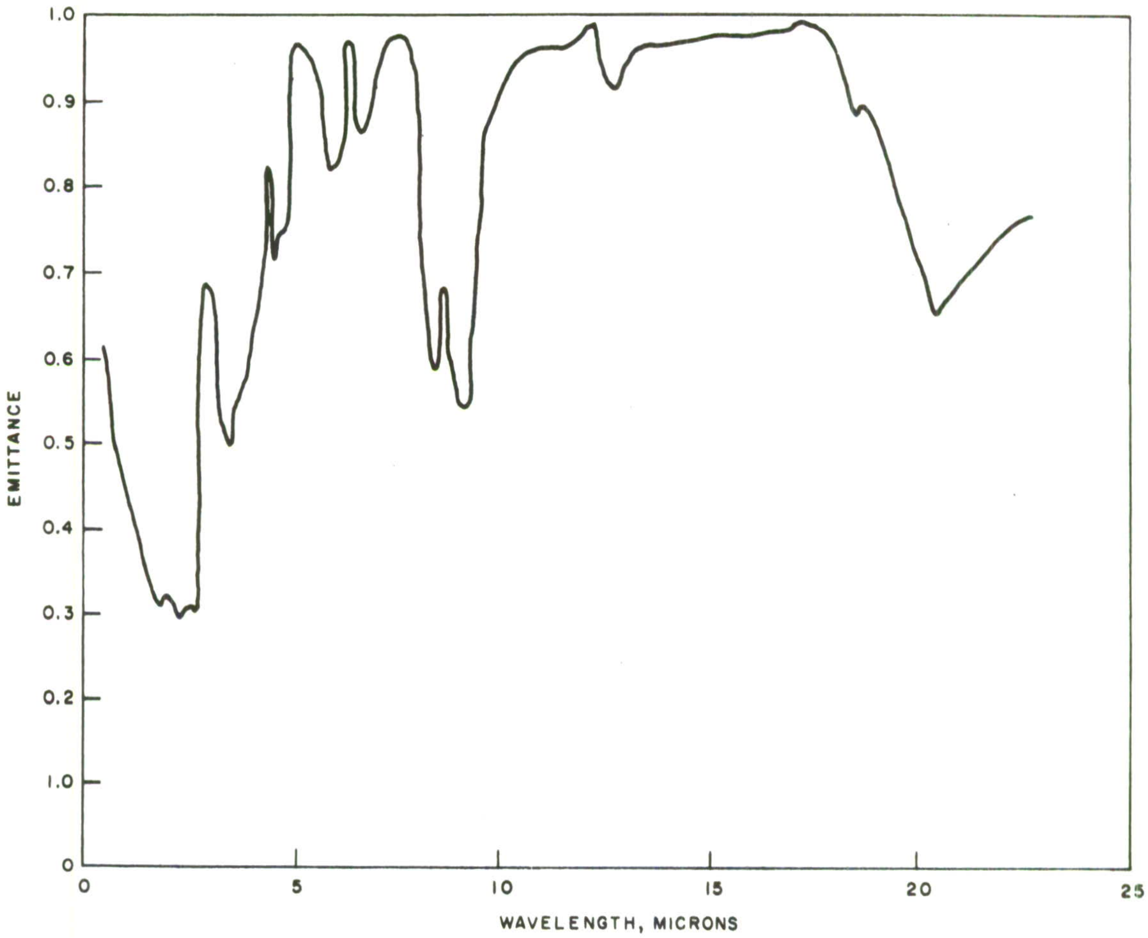

FIG. 24. Spectral Emittance of Beach Sand.

SPECTRAL EMITTANCE OF GYPSUM SAND

Test Method

Over the range of 2.5 to 22 microns, reflectance measurements were made with a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Author presented graph of reflectance versus wavelength.

Sample Temperature

At or near room temperature.

Comments

Pronounced minimum at 8.6 microns.

Locale

White Sands National Monument, White Sands, New Mexico.

Source

Ref. 9, Fig. 12.

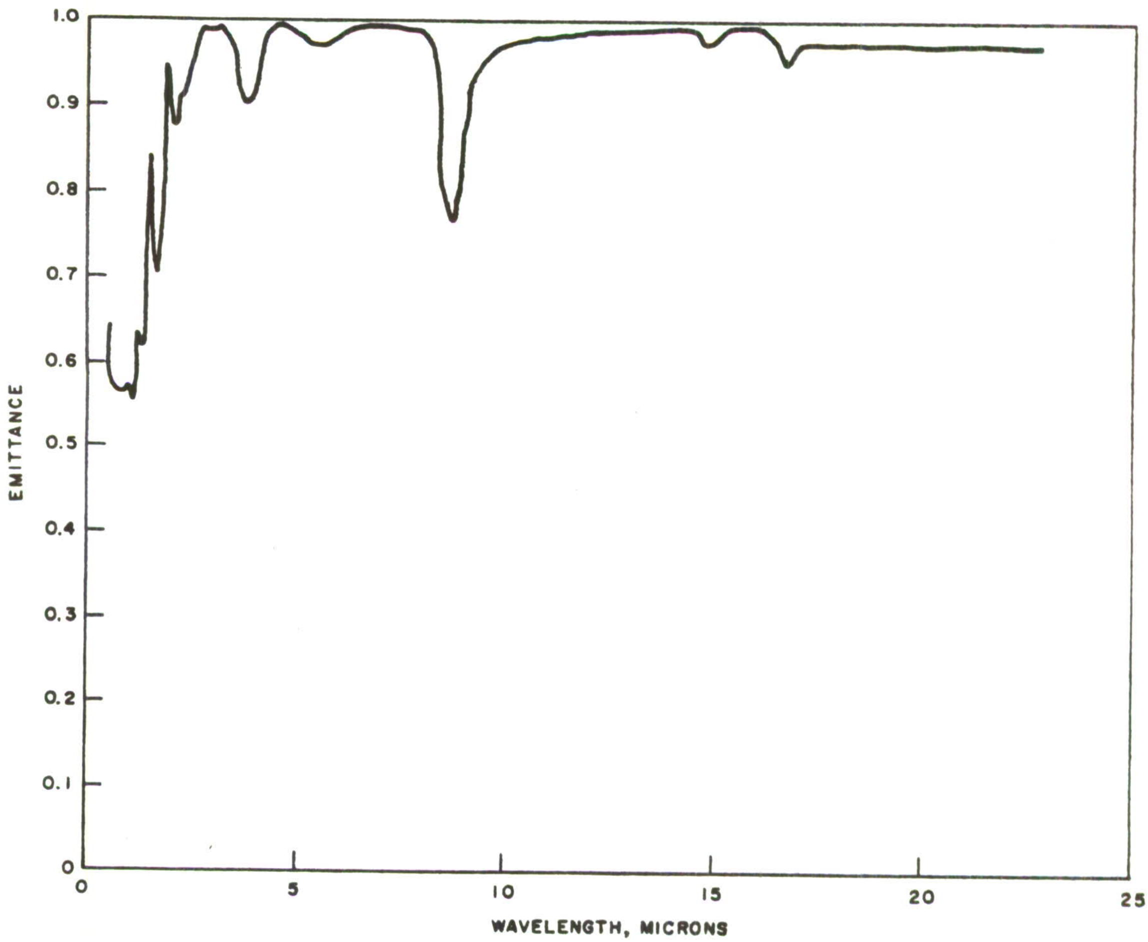

FIG. 25. Spectral Emittance of Gypsum Sand.

SPECTRAL EMITTANCE OF DIRT (DARK), DUSTED ON FLAT BLACK PAINT

Test Method

Reflectance was measured with a Gier-Dunkle heated cavity reflectometer. A Perkin-Elmer spectrometer was used.

Form of Original Data Presentation

Authors presented tables of reflectivity as a function of wavelength.

Sample Temperature

At or near room temperature.

Treatment

Sample material was ground into a powder and dusted upon an aluminum disk covered with flat black paint.

Comments

Mineral samples were supplied by a shop dealing in such specimens. Data for "light" dirt on flat black paint was very similar.

Source

Ref. 30, p. 11.

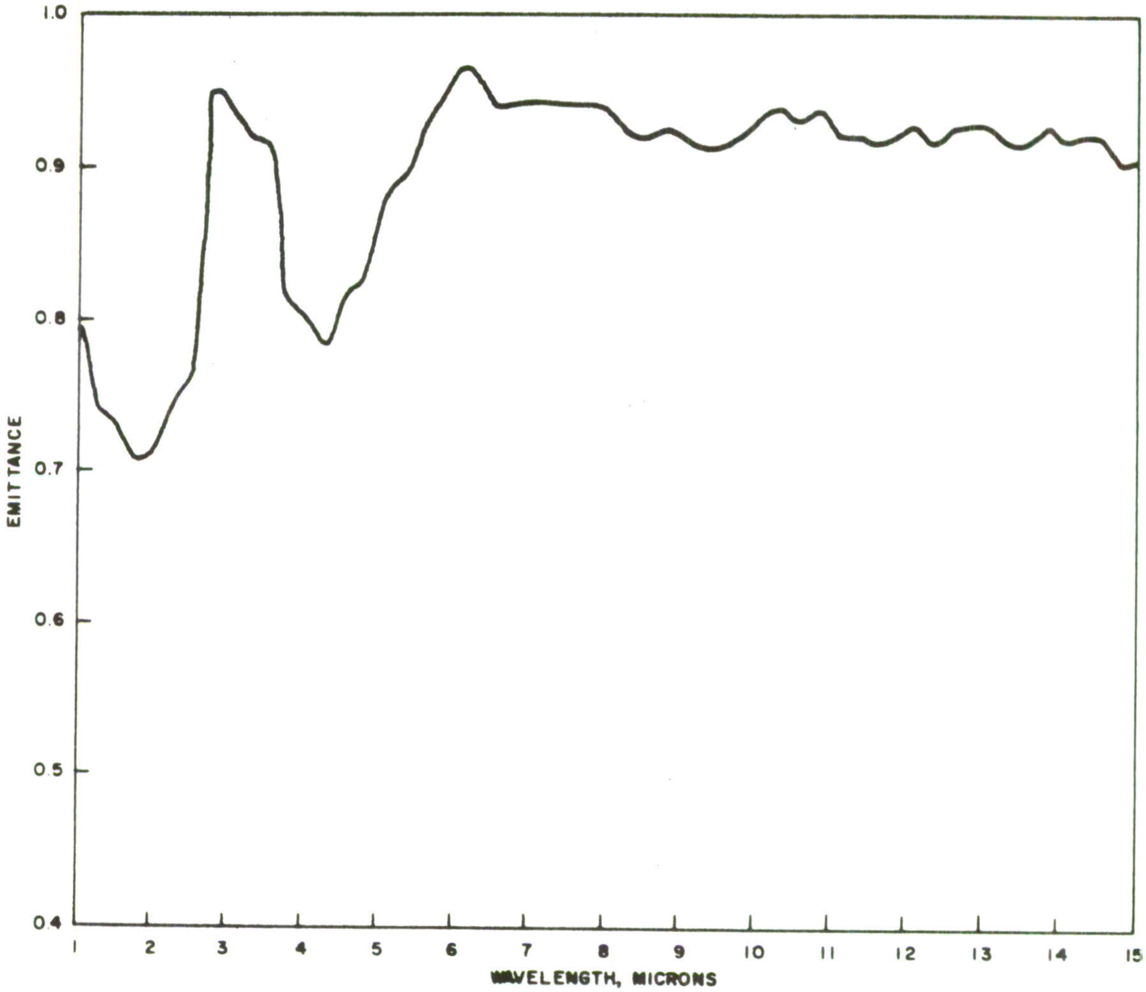

FIG. 26. Spectral Emittance of Dirt (Dark), Dusted on Flat Black Paint.

SPECTRAL EMITTANCE OF PYRITE POWDER, DUSTED ON FLAT BLACK PAINT

Test Method

Reflectance was measured with a Gier-Dunkle heated cavity reflectometer. A Perkin-Elmer spectrometer was used.

Form of Original Data Presentation

Authors presented tables of reflectivity as a function of wavelength.

Sample Temperature

At or near room temperature.

Treatment

Sample material was ground into a powder and dusted upon an aluminum disk covered with flat black paint. Particle sizes were not separated.

Comments

Mineral samples were supplied by a shop dealing in such specimens.

Source

Ref. 30, p. 13.

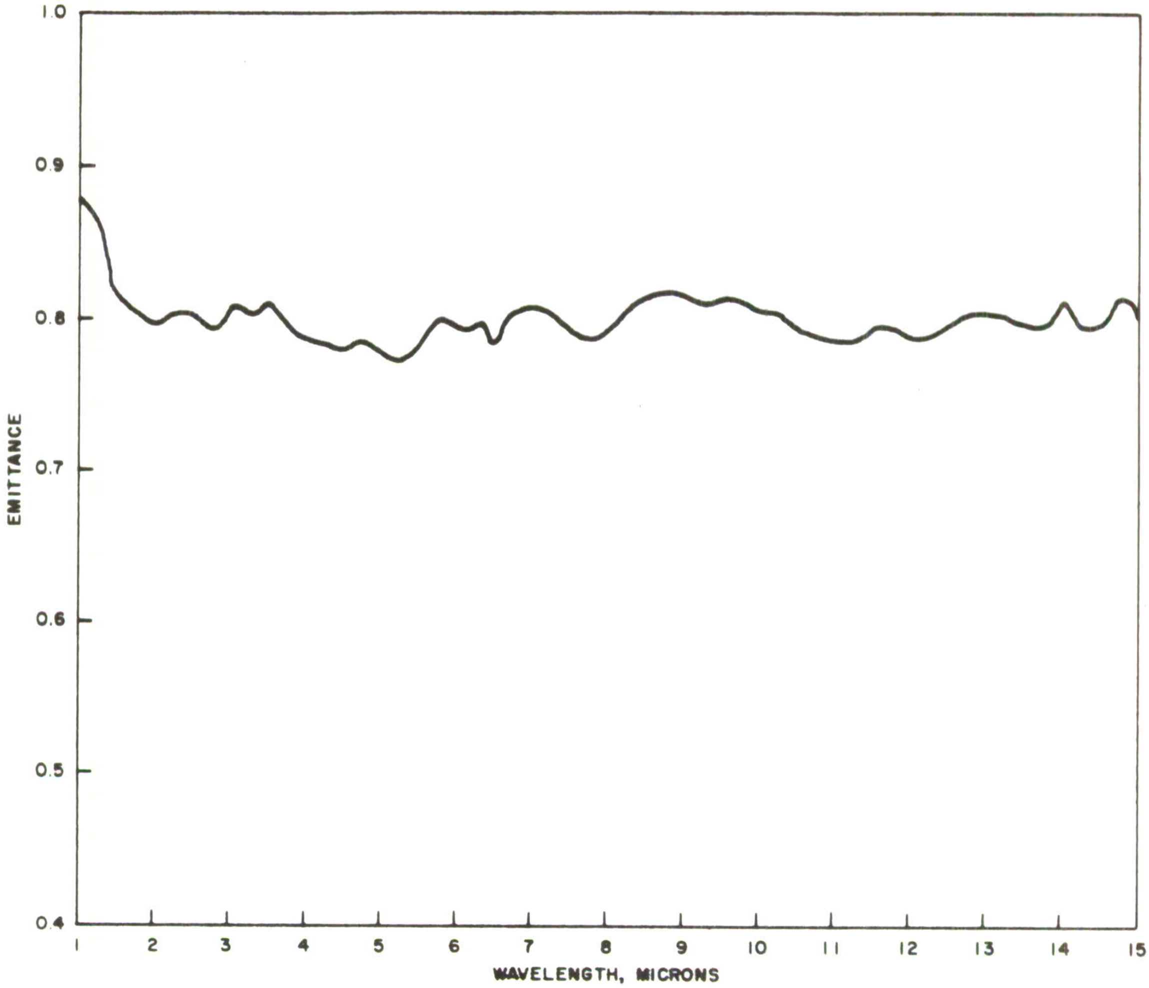

FIG. 27. Spectral Emittance of Pyrite Powder, Dusted On Flat Black Paint.

SPECTRAL EMITTANCE OF QUARTZ SAND, DUSTED ON FLAT BLACK PAINT

Test Method

Reflectance was measured with a Gier-Dunkle heated cavity reflectometer. A Perkin-Elmer spectrometer was used.

Form of Data Presented

Authors presented tables of reflectivity as a function of wavelength.

Sample Temperature

At or near room temperature.

Treatment

Sample material was ground into a powder and dusted upon an aluminum disk covered with flat black paint. Particle sizes were not separated.

Comments

Mineral samples were supplied by a shop dealing in such specimens.

Locale

Monterey.

Source

Ref. 30, p. 14.

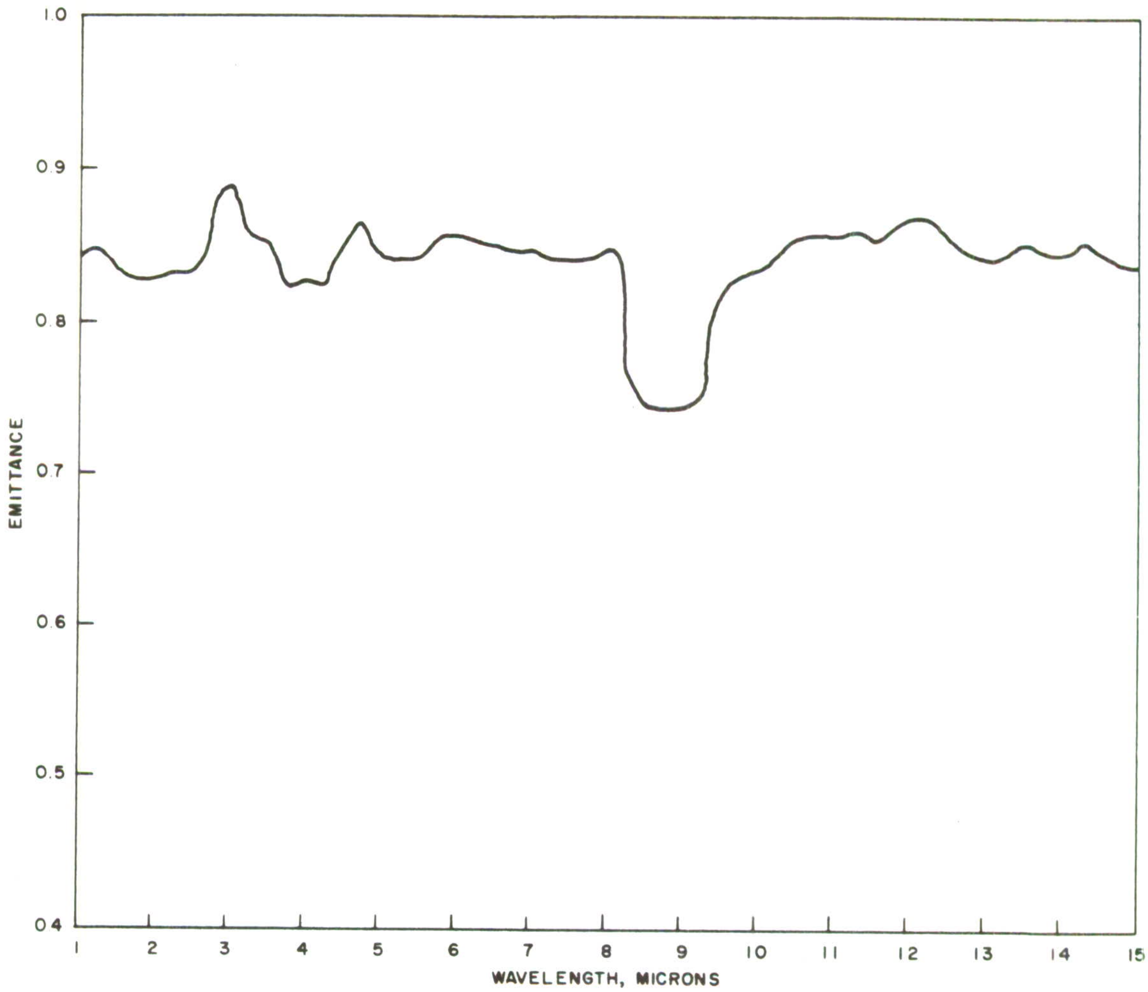

FIG. 28. Spectral Emittance of Quartz Sand, Dusted On Flat Black Paint.

SPECTRAL EMITTANCE OF DIRT (DARK), DUSTED ON SODIUM SILICATE

Test Method

Reflectance was measured with a Gier-Dunkle heated cavity reflectometer. A Perkin-Elmer spectrometer was used.

Form of Original Data Presentation

Authors presented tables of reflectivity as a function of wavelength.

Sample Temperature

At or near room temperature.

Treatment

Sample material was ground into a powder and dusted upon an aluminum disk covered with sodium silicate. Particle sizes were not separated.

Comments

Mineral samples were supplied by a shop dealing in such specimens.

Source

Ref. 30, p. 11.

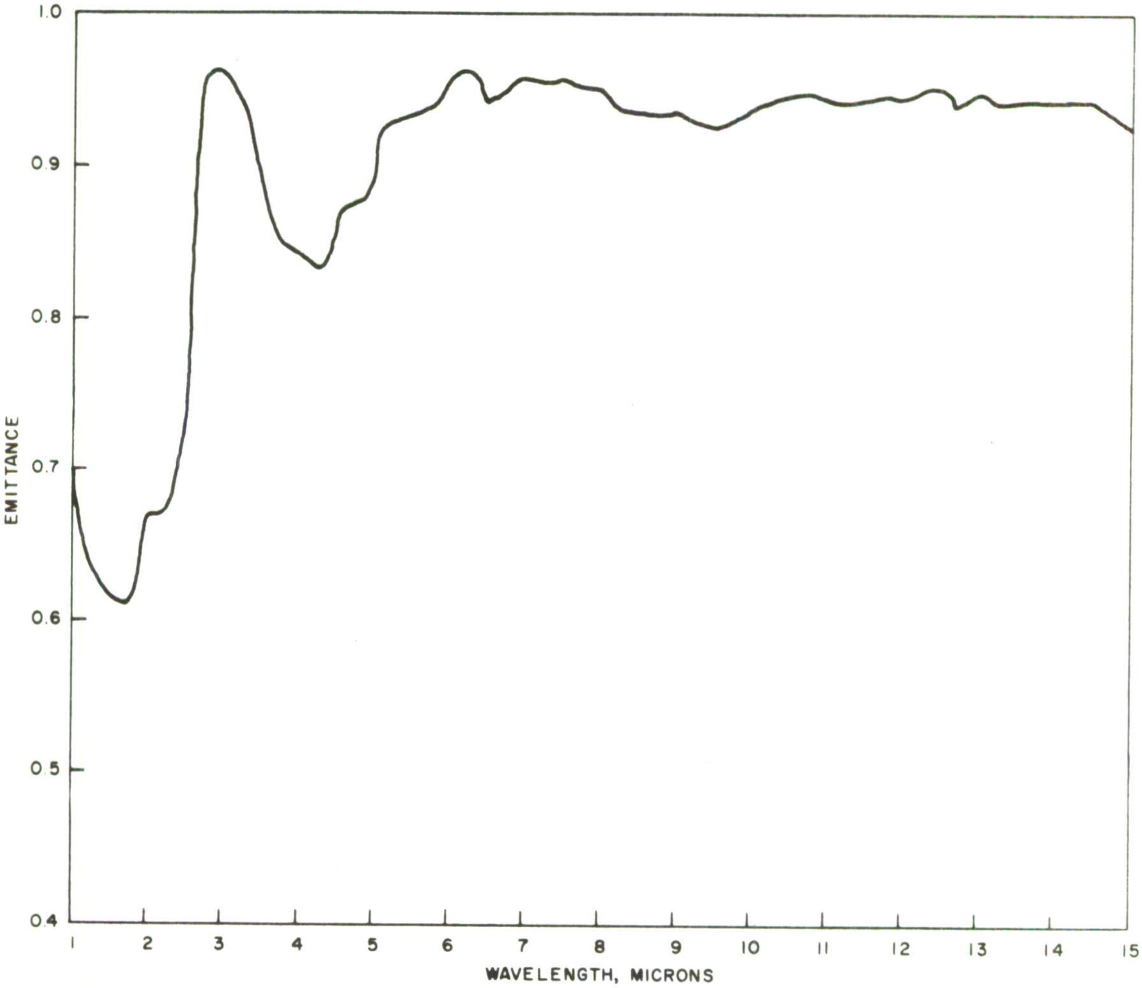

FIG. 29. Spectral Emittance of Dirt (Dark), Dusted On Sodium Silicate.

SPECTRAL EMITTANCE OF DIRT (LIGHT), DUSTED ON SODIUM SILICATE

Test Method

Reflectance was measured with a Gier-Dunkle heated cavity reflectometer. A Perkin-Elmer spectrometer was used.

Form of Original Data Presentation

Authors presented tables of reflectivity as a function of wavelength.

Sample Temperature

At or near room temperature.

Treatment

Sample material was ground into a powder and dusted upon an aluminum disk covered with sodium silicate. Particle sizes were not separated.

Comments

Mineral samples were supplied by a shop dealing in such specimens.

Source

Ref. 30, p. 11.

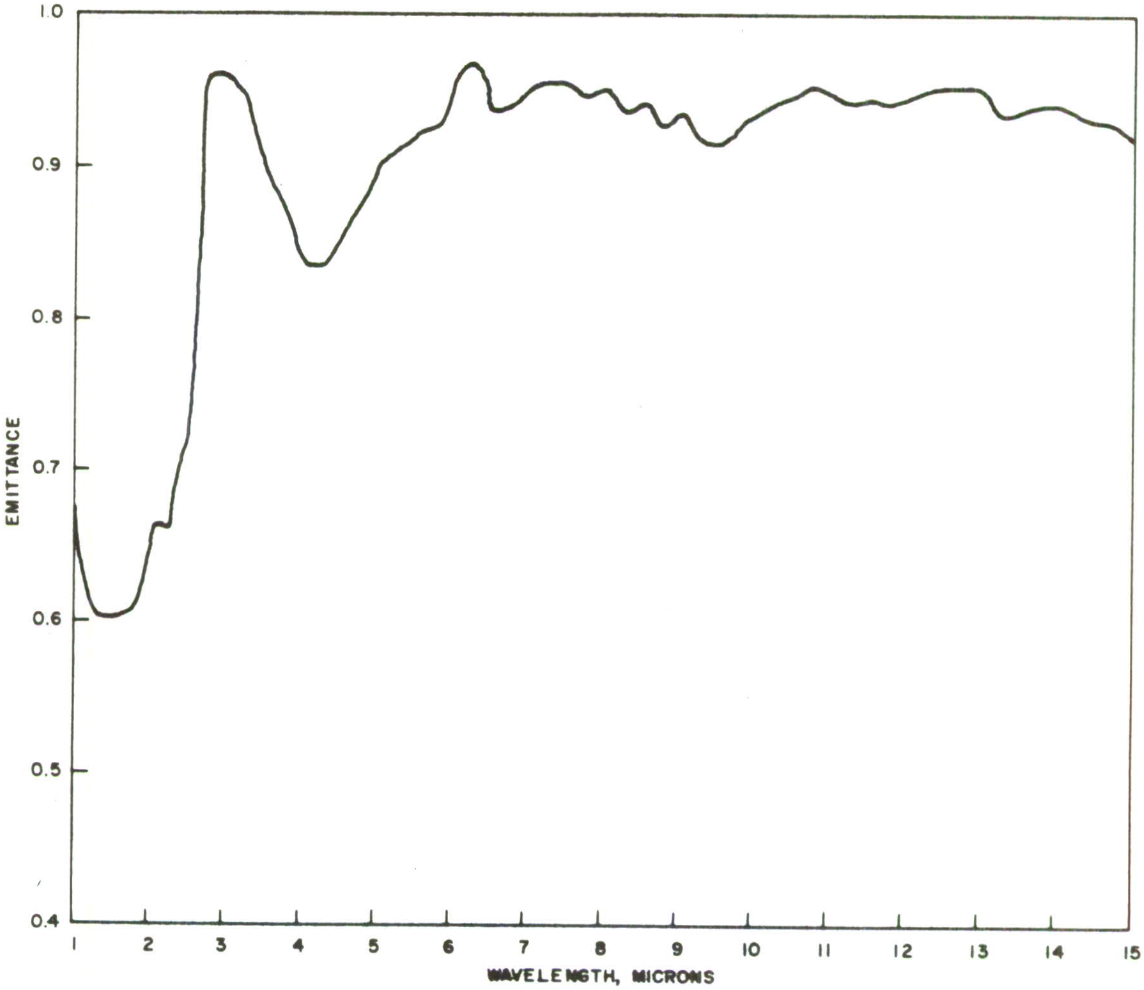

FIG. 30. Spectral Emittance of Dirt (Light), Dusted On Sodium Silicate.

SPECTRAL EMITTANCE OF QUARTZ SAND, DUSTED ON SODIUM SILICATE

Test Method

Reflectance was measured with a Gier-Dunkle heated cavity reflectometer. A Perkin-Elmer spectrometer was used.

Form of Original Data Presentation

Authors presented tables of reflectivity as a function of wavelength.

Sample Temperature

At or near room temperature.

Treatment

Sample material was ground into a powder and dusted upon an aluminum disk covered with sodium silicate. Particle sizes were not separated.

Comments

Mineral samples were supplied by a shop dealing in such specimens.

Locale

Monterey.

Source

Ref. 30, p. 14.

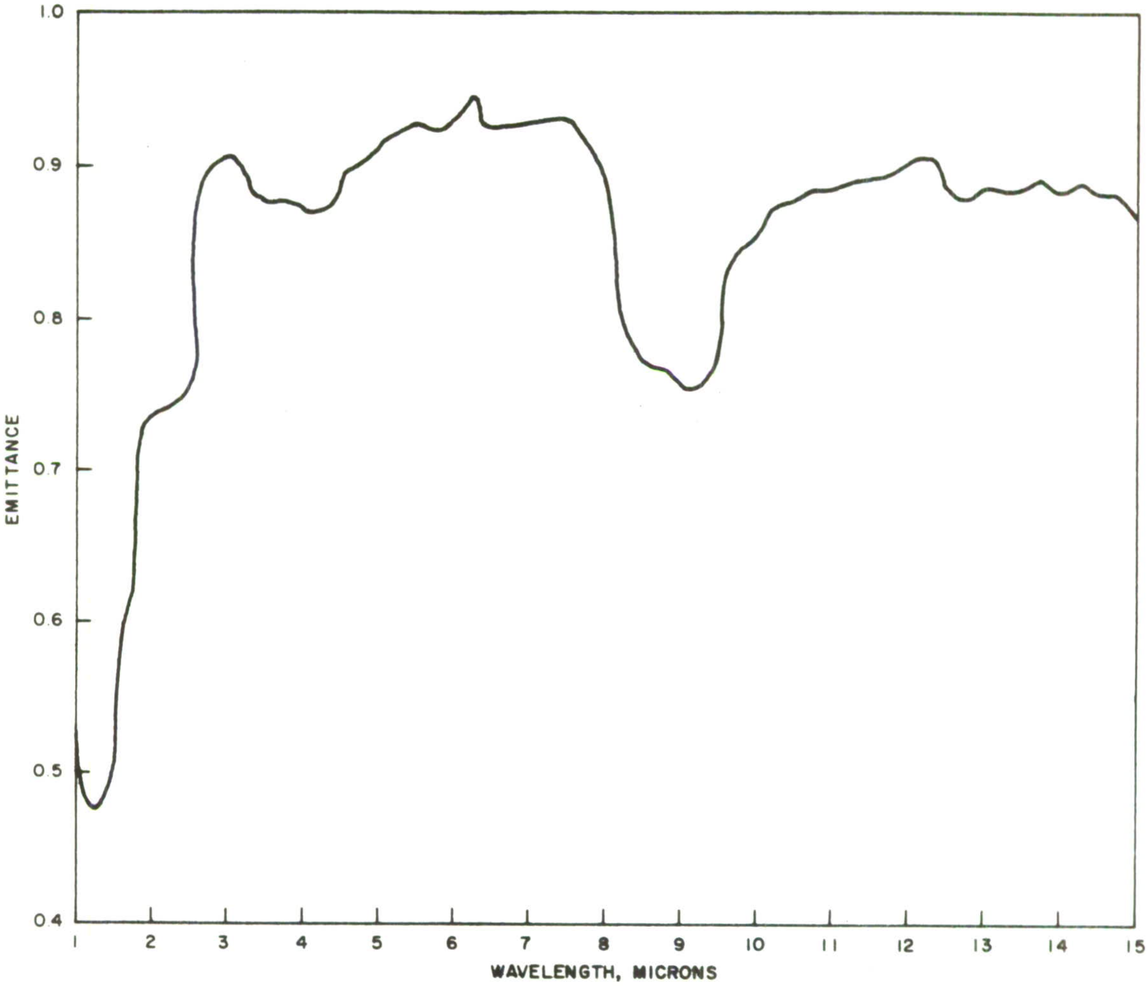

FIG. 31. Spectral Emittance of Quartz Sand, Dusted On Sodium Silicate.

SPECTRAL EMITTANCE OF SOIL

Test Method

Over the range of 2.5 to 22 microns, total reflectance measurements were made with a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Author presented graph of reflectance versus wavelength.

Sample Temperature

At or near room temperature.

Comments

The data for this sample showed general characteristics similar to that of another sample taken from Rosamond Dry Lake, California.

Locale

Pawnee Grassland, Colorado.

Source

Ref. 9, Fig. 13.

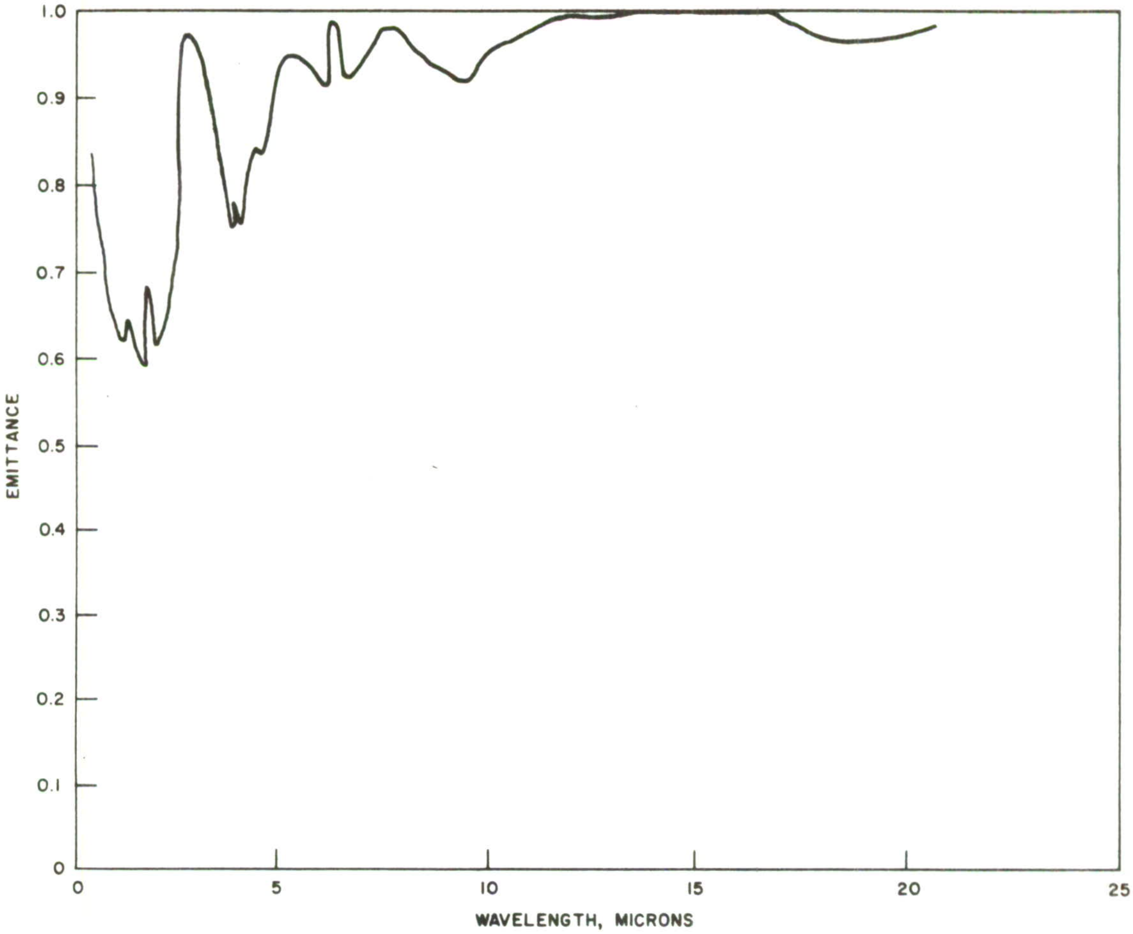

FIG. 32. Spectral Emittance of Soil.

SPECTRAL EMITTANCE OF DESERT SOIL

Test Method

Over the range of 2.5 to 22 microns, total reflectance measurements were made with a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Author presented graph of reflectance versus wavelength.

Sample Temperature

At or near room temperature.

Locale

Mojave Desert.

Source

Ref. 9, Fig. 8.

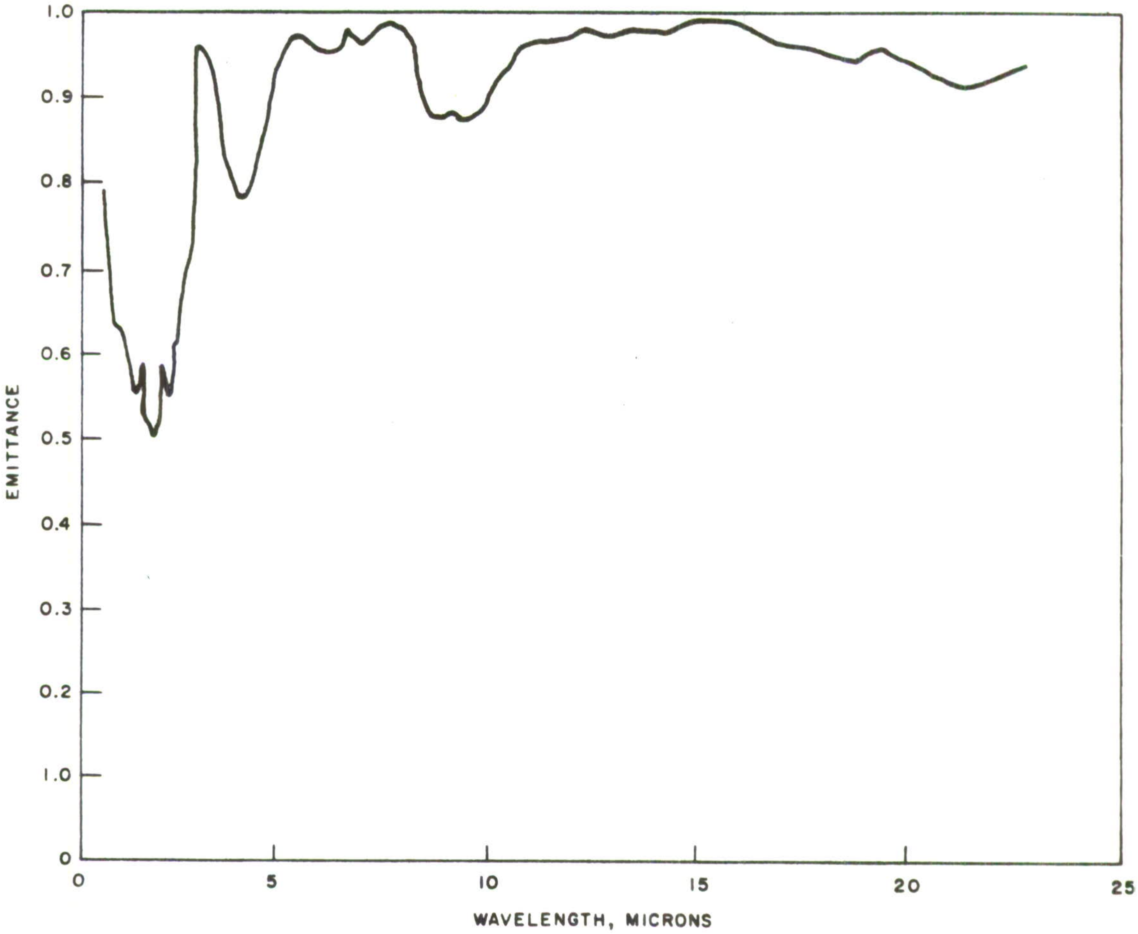

FIG. 33. Spectral Emittance of Desert Soil.

SPECTRAL EMITTANCE OF "BAD WATER CLAY"

Test Method

Over the range of 2.5 to 22 microns, total reflectance measurements were made with a Cary Model 90 double-beam spectrophotometer equipped with total reflectance attachments.

Form of Original Data Presentation

Author presented graph of reflectance versus wavelength.

Sample Condition

Used in a state resembling as closely as possible that of natural occurrence.

Locale

Death Valley, California.

Source

Ref. 9, Fig. 11.

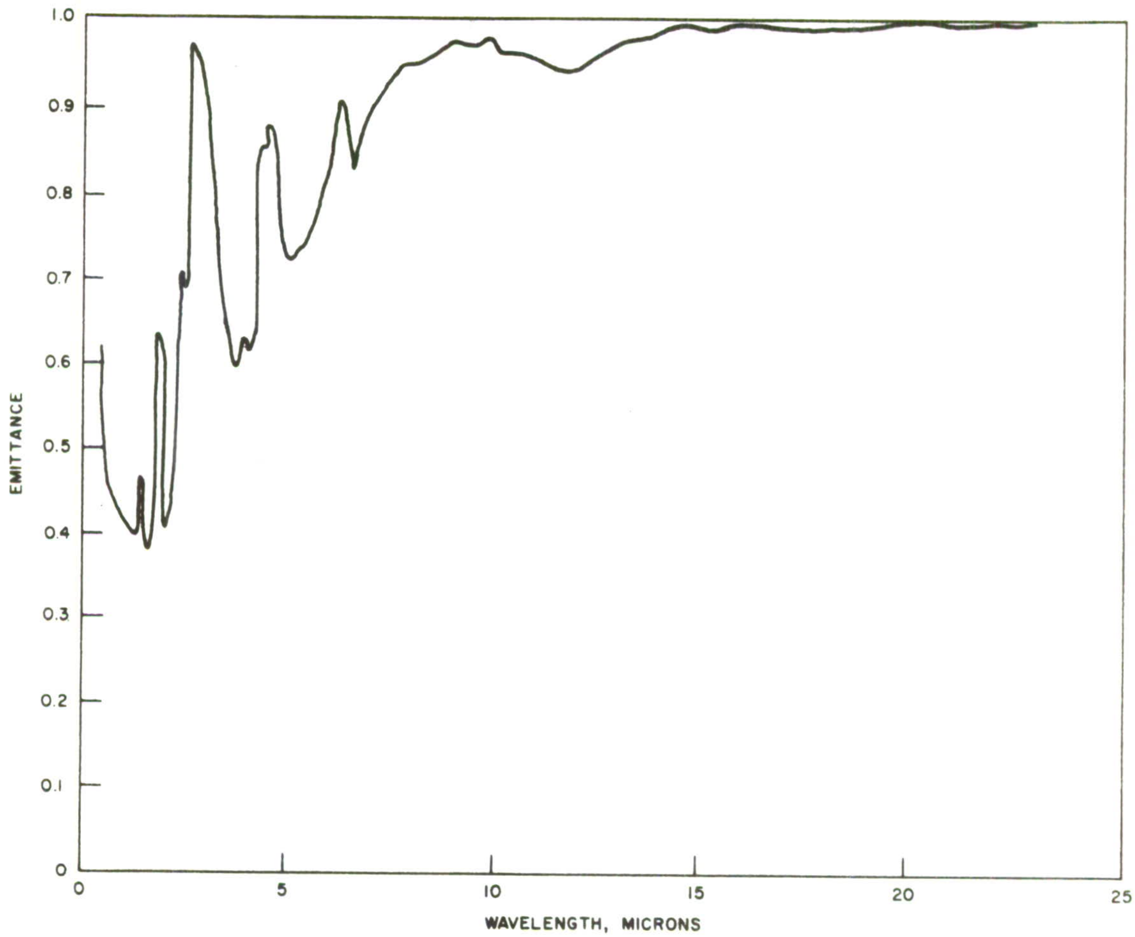

FIG. 34. Spectral Emittance of "Bad Water Clay".

EMITTANCE OF FOLIAGE, BARK, AND GRASS

Only one author (Ref. 21) has been drawn upon to provide all of the information in this section. This was the only report which presented well-defined information for spectral emittance of leaves and plant materials. Reference 6 reported spectral emittance plots for leaves of plants, but the scales were logarithmic, and the character of the curve was very ill-defined in the 8- to 14-micron region.

Judging from material uncovered in information searches concerning emittance of plants, trees, and grass, there is evidently a large information lack for many different species of trees and grasses. No measurement information was available on crop materials in the 8- to 14-micron wavelength range.

TOTAL DIFFUSE SPECTRAL EMITTANCE OF A YOUNG WILLOW LEAF (SALIX FRAGILIS)

Test Method

Total diffuse reflectance was measured in a Coblentz Hemisphere using a Golay detector and a single-beam Perkin-Elmer infrared spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength. Data points were shown at least every 0.5 micron and usually much closer.

Sample Temperature

Near room temperature.

Sample Condition

Dry, top side.

Comments

Data were corrected to account for modified use of detector apparatus. Variations in emittance results for leaves from the same branch of a tree were small; most of the differences occurred in the regions below 3 microns. In presenting this data as emittance, it is assumed that transmission was not significant and the leaf may be treated as an opaque object.

Source

Ref. 21, Fig. 2-2.

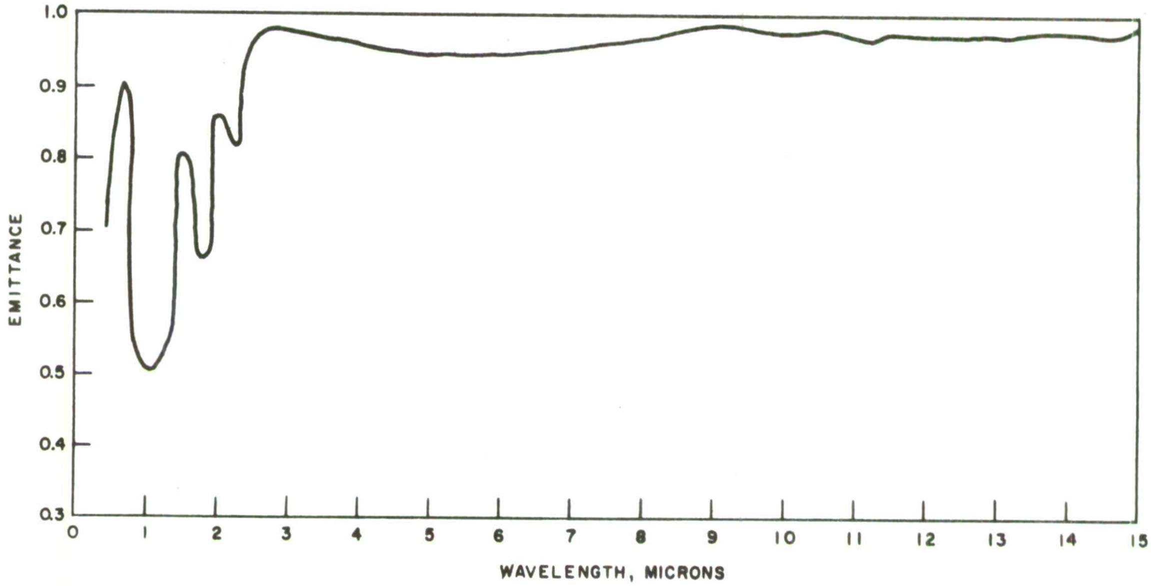

FIG. 35. Total Diffuse Spectral Emittance of a Young Willow Leaf (Salix Fragilis).

TOTAL DIFFUSE SPECTRAL EMITTANCE OF GREEN CONIFEROUS TWIGS
(JACK PINE, PINUS BANKSIANA)

Test Method

Total diffuse reflectance was measured in a Coblentz Hemisphere using a Golay detector and a single-beam Perkin-Elmer infrared spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength. Data points were shown at least every 0.5 micron and usually much closer.

Sample Temperature

Near room temperature.

Sample Condition

Dry.

Comments

Data corrected to account for modified use of detector apparatus. In presenting this data as emittance it is assumed that the transmission of the example was negligible.

Locale

Northeastern America.

Source

Ref. 21, Fig. 2-7.

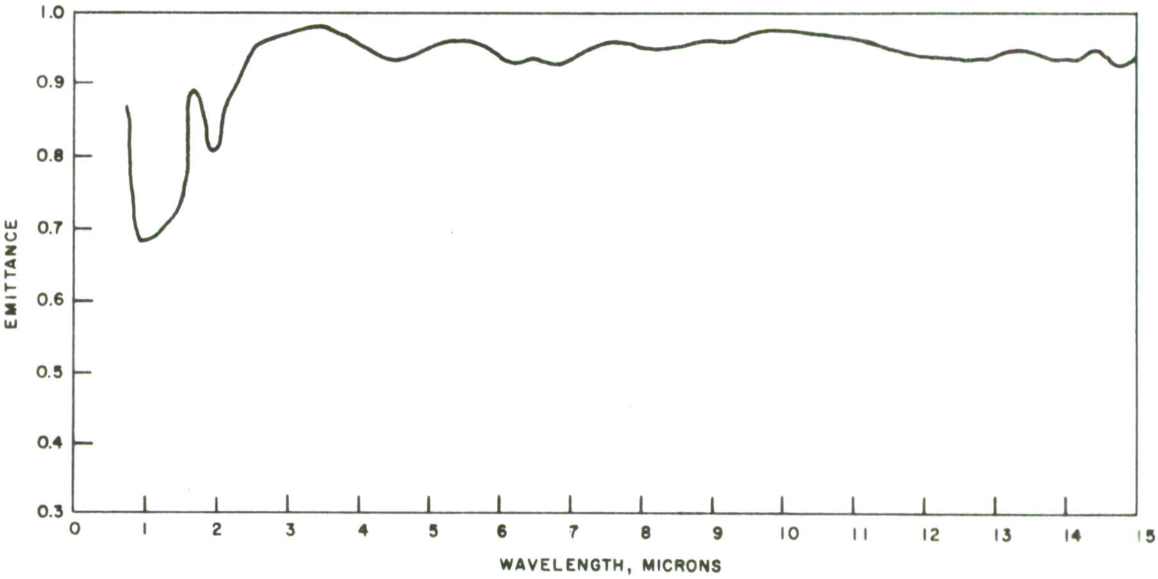

FIG. 36. Total Diffuse Spectral Emittance of Green Coniferous Twigs (Jack Pine, Pinus Banksiana).

TOTAL DIFFUSE SPECTRAL EMITTANCE OF OAK LEAF (QUERCUS BOREALIS MAXIMA)

Test Method

Total diffuse reflectance was measured in a Coblentz Hemisphere using a Golay detector and a single-beam Perkin-Elmer infrared spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength. Data points were shown at least every 0.5 micron and usually much closer.

Sample Temperature

Near room temperature.

Sample Condition

Winter color, dry, top side.

Comments

Data corrected to account for modified use of detector apparatus. Variations in emittance results for leaves from the same branch of a tree were small; most of the differences occurred in the regions below 3 microns. In presenting this data as emittance, it is assumed that transmission was not significant and the leaf may be treated as an opaque object.

Locale

Eastern North America.

Source

Ref. 21, Fig. 2-6.

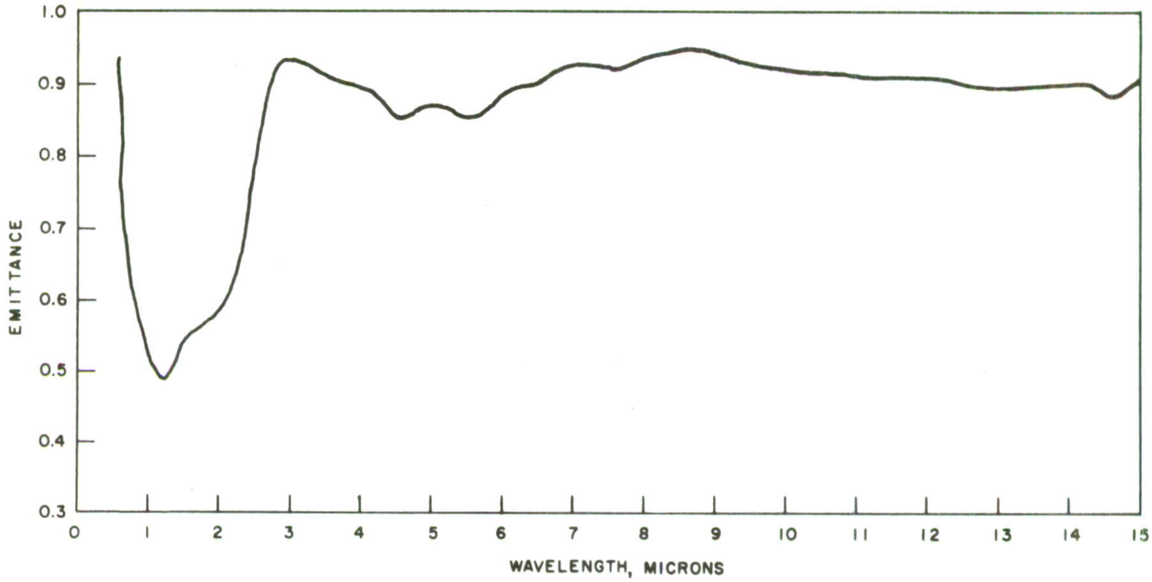

FIG. 37. Total Diffuse Spectral Emittance of Oak Leaf (Quercus Borealis Maxima).

TOTAL DIFFUSE SPECTRAL EMITTANCE OF MAPLE LEAF (ACER RUBRUM)

Test Method

Total diffuse reflectance was measured in a Coblentz Hemisphere using a Golay detector and a single-beam Perkin-Elmer infrared spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength. Data points were shown at least every 0.5 micron and usually much closer.

Sample Temperature

Near room temperature.

Sample Condition

Pressed, dormant, dry.

Comments

Data were corrected to account for modified use of detector apparatus. Variations in emittance results for leaves from the same branch of a tree were small; most of the differences occurred in the regions below 3 microns. In presenting this data as emittance, it is assumed that transmission was not significant and the leaf may be treated as an opaque object.

Locale

Eastern North America.

Source

Ref. 21, Fig. 2-5.

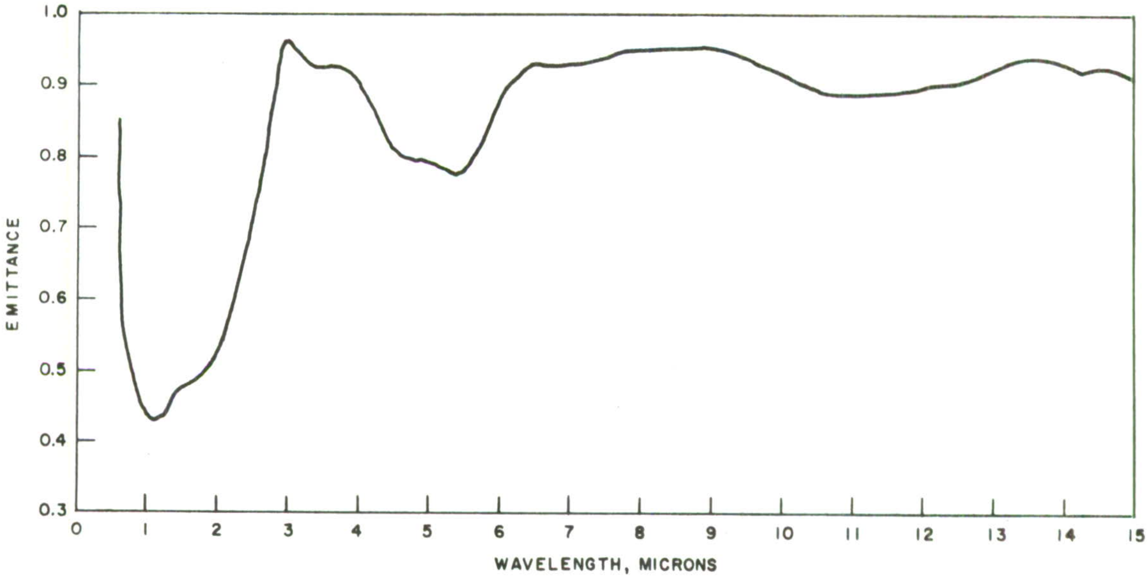

FIG. 38. Total Diffuse Spectral Emittance of Maple Leaf (Acer Rubrum).

TOTAL DIFFUSE SPECTRAL EMITTANCE OF GREEN MOUNTAIN LAUREL (KALMIA LARIFOLIA)

Test Method

Total diffuse reflectance was measured in a Coblentz Hemisphere using a Golay detector and a single-beam Perkin-Elmer infrared spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength. Data points were shown at least every 0.5 micron and usually much closer.

Sample Temperature

Near room temperature.

Sample Condition

Dry, top side.

Comments

Data were corrected to account for modified use of detector apparatus. Variations in emittance results for leaves from the same branch of a tree were small; most of the differences occurred in the regions below 3 microns. In presenting this data as emittance, it is assumed that transmission was not significant and the leaf may be treated as an opaque object.

Source

Ref. 21, Fig. 2-1.

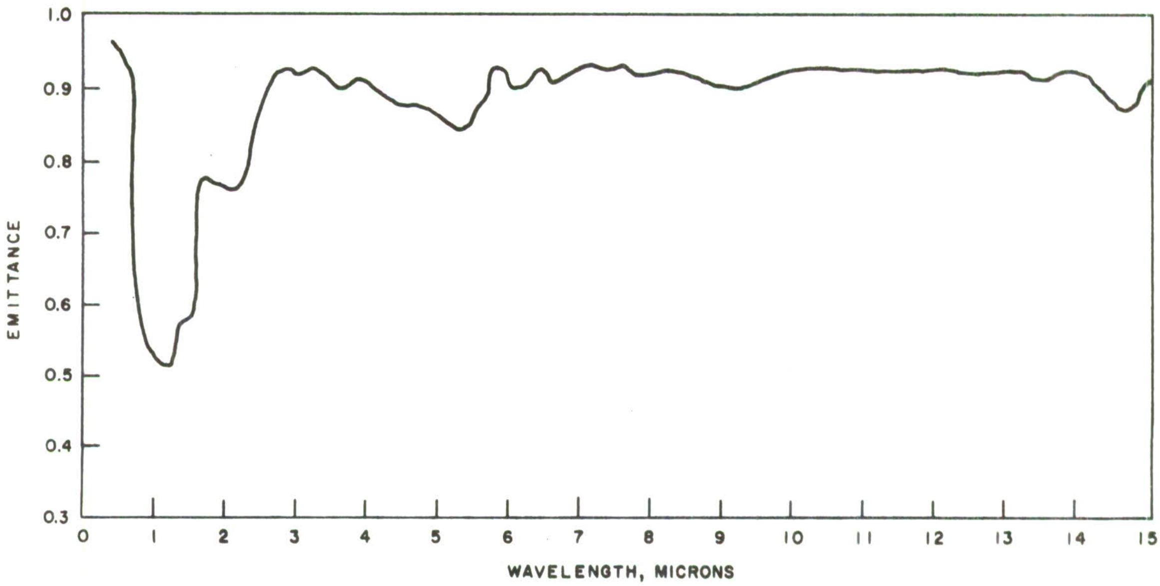

FIG. 39. Total Diffuse Spectral Emittance of Green Mountain Laurel (Kalmia Larifolia).

TOTAL DIFFUSE SPECTRAL EMITTANCE OF HOLLY LEAF (ILEX ALTACLARENSIS)

Test Method

Total diffuse reflectance was measured in a Coblentz Hemisphere using a Golay detector and a single-beam Perkin-Elmer infrared spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength. Data points were shown at least every 0.5 micron and usually much closer.

Sample Temperature

Near room temperature.

Sample Condition

Dry.

Surface

Both top and bottom surfaces measured and are shown.

Comments

Data were corrected to account for modified use of detector apparatus. Variations in emittance results for leaves from the same branch of a tree were small; most of the differences occurred in the regions below 3 microns. In presenting this data as emittance, it is assumed that transmission was not significant and the leaf may be treated as an opaque object.

Source

Ref. 21, Fig. 2-3 and 2-4.

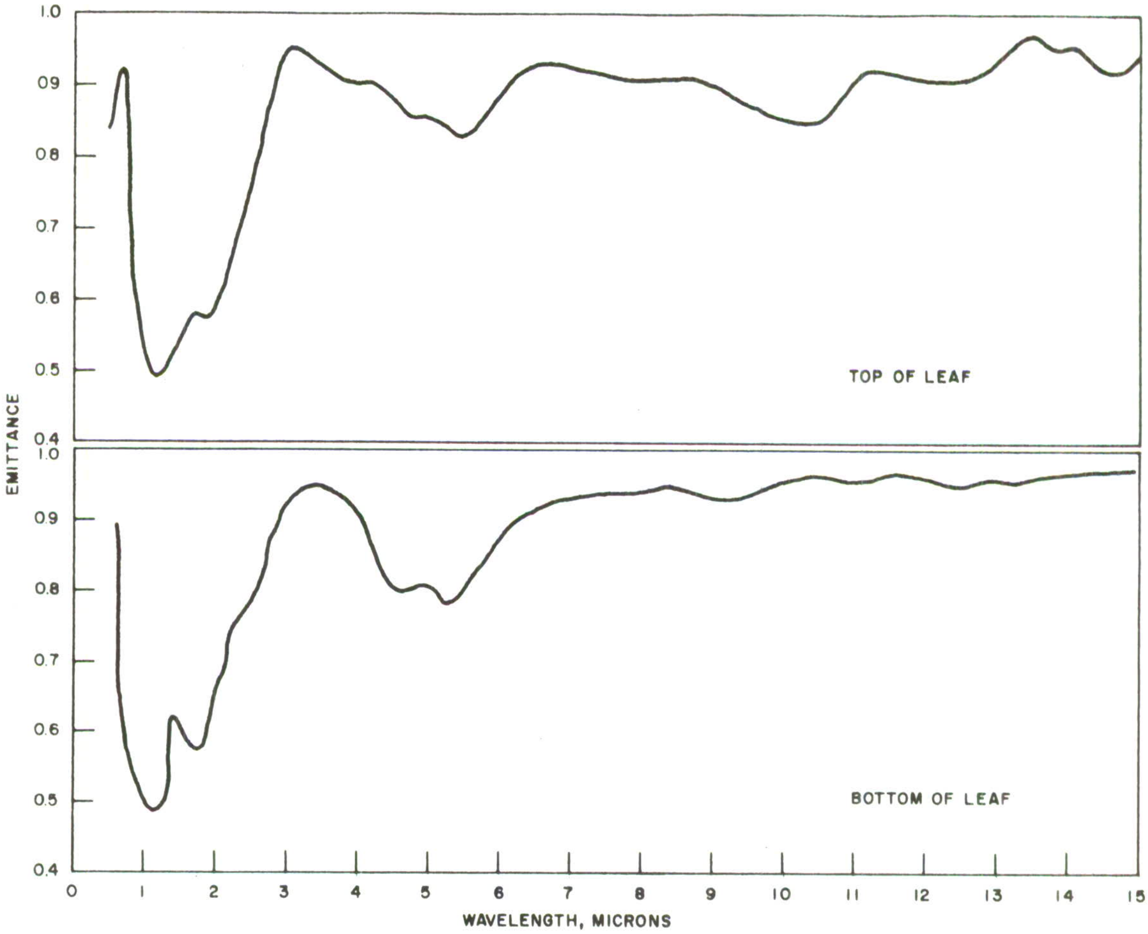

FIG. 40. Total Diffuse Spectral Emittance of Holly Leaf (Ilex Altaclarensis).

TOTAL DIFFUSE SPECTRAL EMITTANCE OF GRASS (MEADOW FESCUE)

Test Method

Total diffuse reflectance was measured in a Coblentz Hemisphere using a Golay detector and a single-beam Perkin-Elmer infrared spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength. Data points were shown at least every 0.5 micron and usually much closer.

Sample Temperature

Near room temperature.

Sample Condition

Dry.

Comments

Data were corrected to account for modified use of detector apparatus. In presenting this data as emittance, it is assumed that transmission was not significant and the leaf may be treated as an opaque object.

Source

Ref. 21, Fig. 2-8.

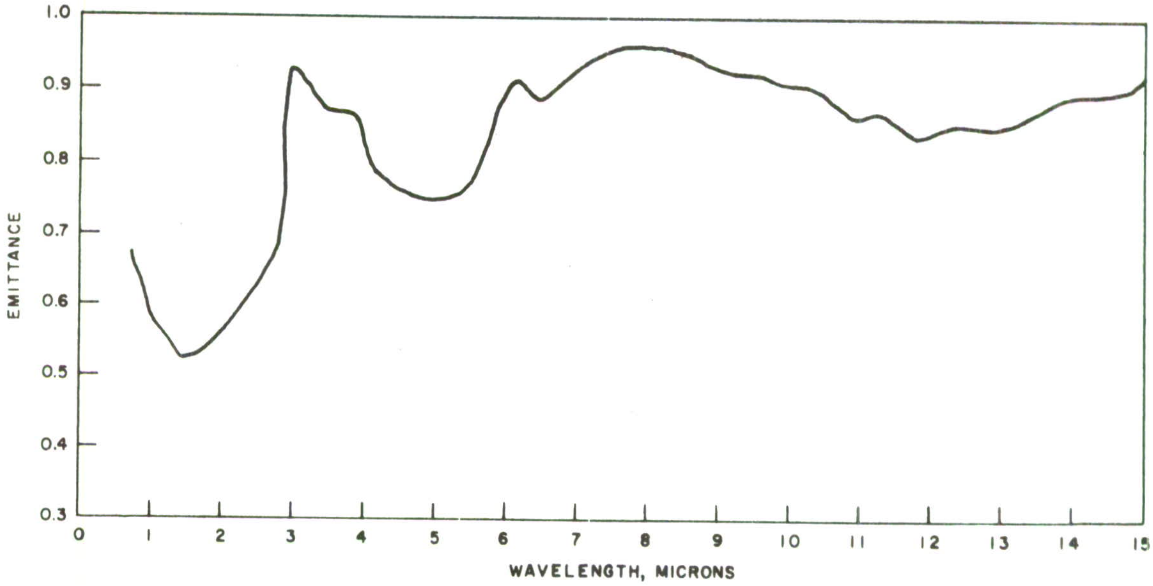

FIG. 41. Total Diffuse Spectral Emittance of Grass (Meadow Fescue).

TOTAL DIFFUSE SPECTRAL EMITTANCE OF JACK PINE BARK (PINUS BANKSIANA)

Test Method

Total diffuse reflectance was measured in a Coblentz Hemisphere using a Golay detector and a single-beam Perkin-Elmer infrared spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength. Data points were shown at least every 0.5 micron and usually much closer.

Sample Temperature

Near room temperature.

Comments

Data were corrected to account for modified use of detector apparatus. Very similar data was obtained for bark from Red Oak (Quercus Borealis Maxima) and Colorado Spruce (Pinus Ponderosa).

Source

Ref. 21, Fig. 2-20.

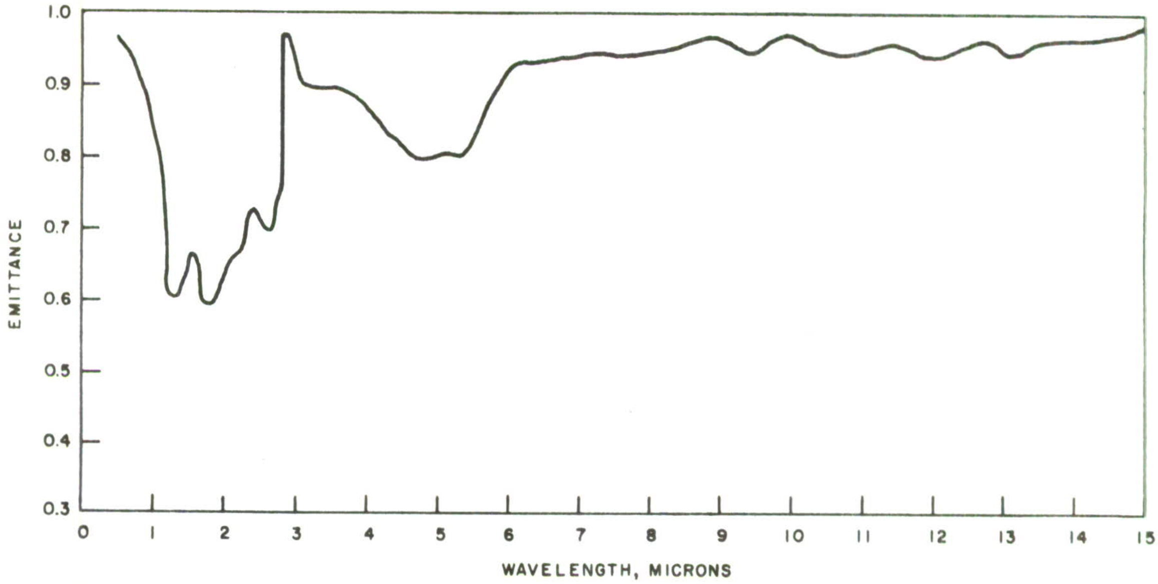

FIG. 42. Total Diffuse Spectral Emittance of Jack Pine Bark (Pinus Banksiana).

SPECTRAL EMITTANCE OF METALS

Information on spectral emittances of metals is more abundant than that in any other category in this report. Sources of information are many and varied.

The effect of surface condition on emittance is evidenced by the difference in the graphs presented for polished aluminum (Fig. 43) and mill-finished aluminum (Fig. 44). Roll-finished aluminum foil (Fig. 45) has a different level and character than the other two finishes. Notice the difference between the samples of black anodized aluminum.

Note also the close agreement between the two separately reported determinations of the spectral emittance of stainless steel, type 321 (Fig. 59 and 60).

Throughout the remainder of this section, the reader should note effects similar to those that were elaborated on for aluminum. Where appropriate information is given, one may observe that:

1. Alloy composition is a significant determinant of the spectral emittance;

2. Surface condition is a critical factor in producing characteristics in the spectral emission of a metal.

3. Surface finish by chemical means is a major determining factor and individual techniques produce large variations.

SPECTRAL EMITTANCE OF POLISHED PURE ALUMINUM

Test Method

Reflectance measurements made using a hemispherical reflector with a Perkin-Elmer Model 112 spectrometer. A Golay detector was used.

Form of Original Data Presentation

Authors presented data as shown here.

Sample Temperature

295°K.

Surface Conditions

No other specifications given besides polished and buffed to a high luster.

Comments

Data presented describes emittances at near-normal incidence (5 deg).

Source

Ref. 12, p. 5-22.

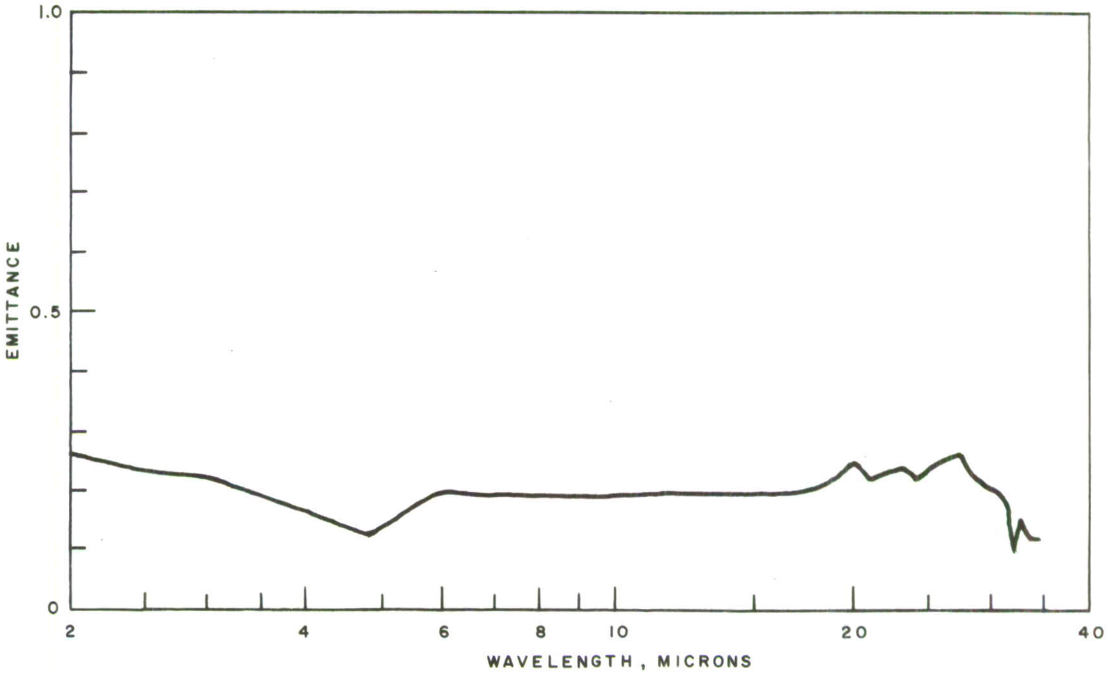

FIG. 43. Spectral Emittance of Polished Pure Aluminum.

SPECTRAL EMITTANCE OF MILL-FINISHED PURE ALUMINUM

Test Method

Reflectance measurements made using a hemispherical reflector with a Perkin-Elmer Model 112 spectrometer. A Golay detector was used.

Form of Original Data Presentation

Authors presented data as shown here.

Sample Temperature

295°K.

Comments

Data presented describes emittance at near-normal incidence (5 deg).

Source

Ref. 12, p. 5-21.

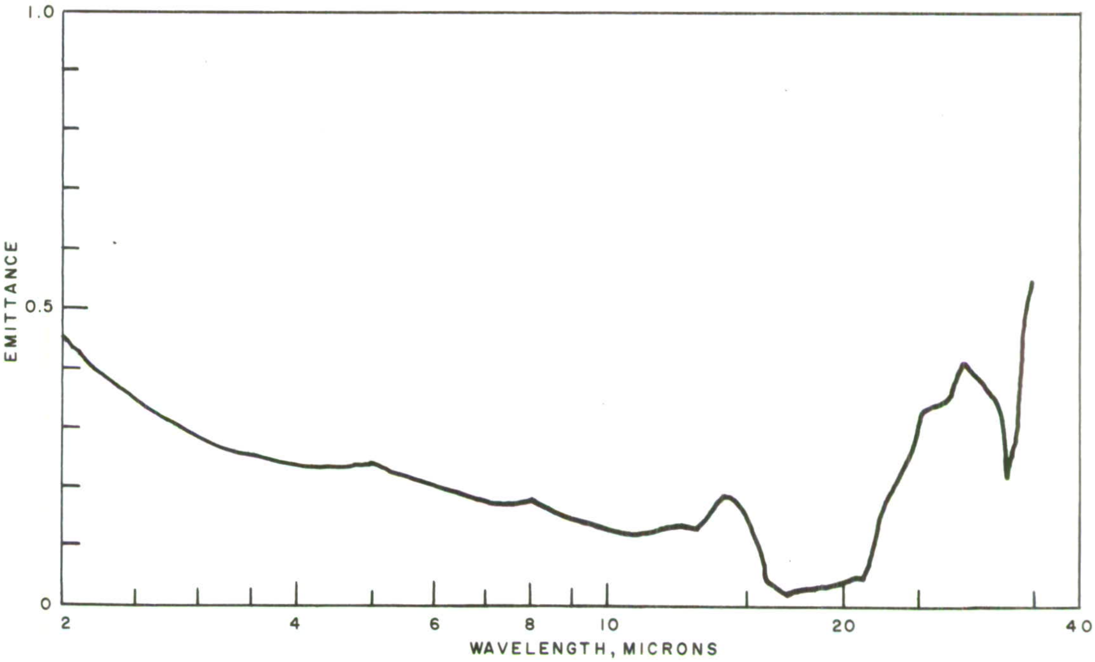

FIG. 44. Spectral Emittance of Mill-Finished Pure Aluminum.

SPECTRAL EMITTANCE OF ALUMINUM FOIL

Test Method

Not mentioned. It was stated that "... reflectances of the samples considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)."

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 17.

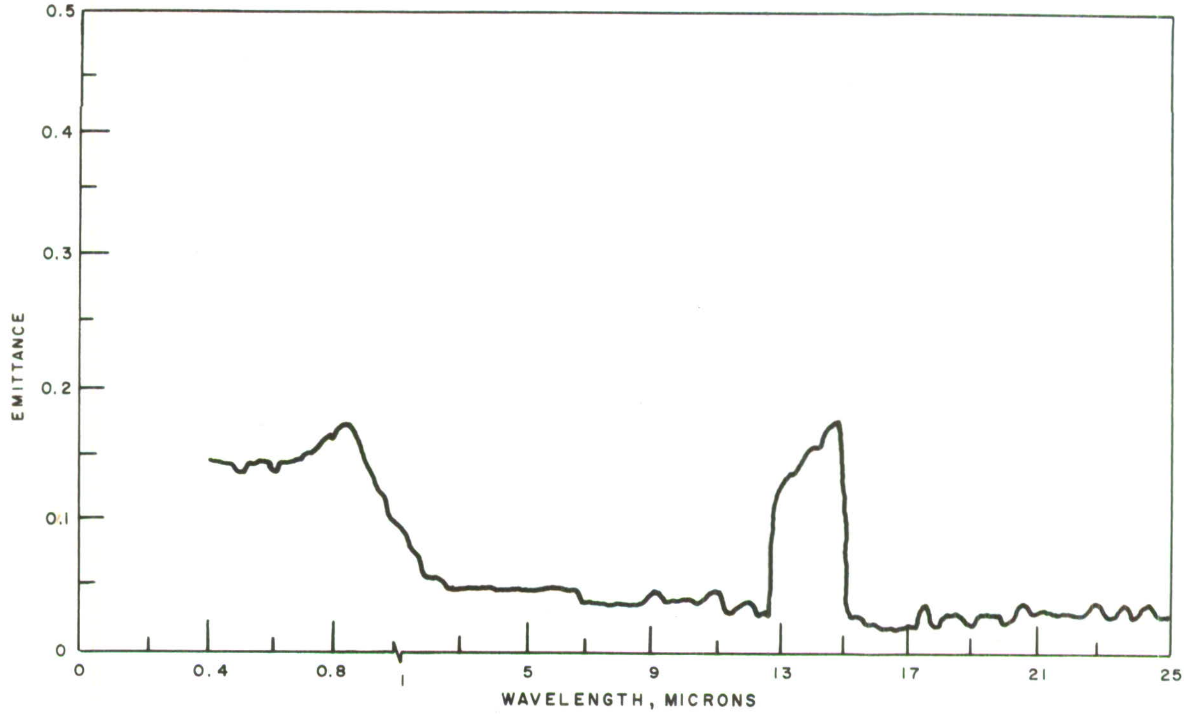

FIG. 45. Spectral Emittance of Aluminum Foil.

NORMAL SPECTRAL EMITTANCE OF BLACK ANODIZED ALUMINUM

Test Method

Emissivity was calculated from reflectance data obtained with a Perkin-Elmer Model 13 monochromator as a dispersing and detecting system with an auxiliary system of optics.

Form of Original Data Presentation

Authors presented data as shown here.

Sample Temperature

323°K.

Source

Ref. 15, App. 11.

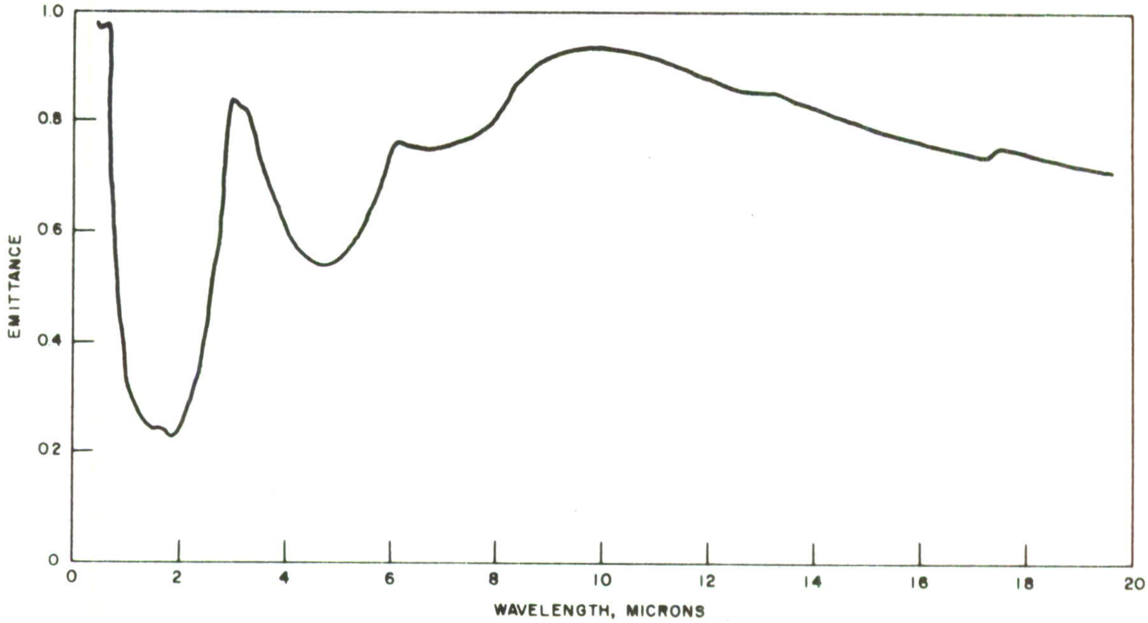

FIG. 46. Normal Spectral Emittance of Black Anodized Aluminum.

SPECTRAL EMITTANCE OF 2024-T3 ALUMINUM

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Sample Condition

125 finish. RMS

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 14.

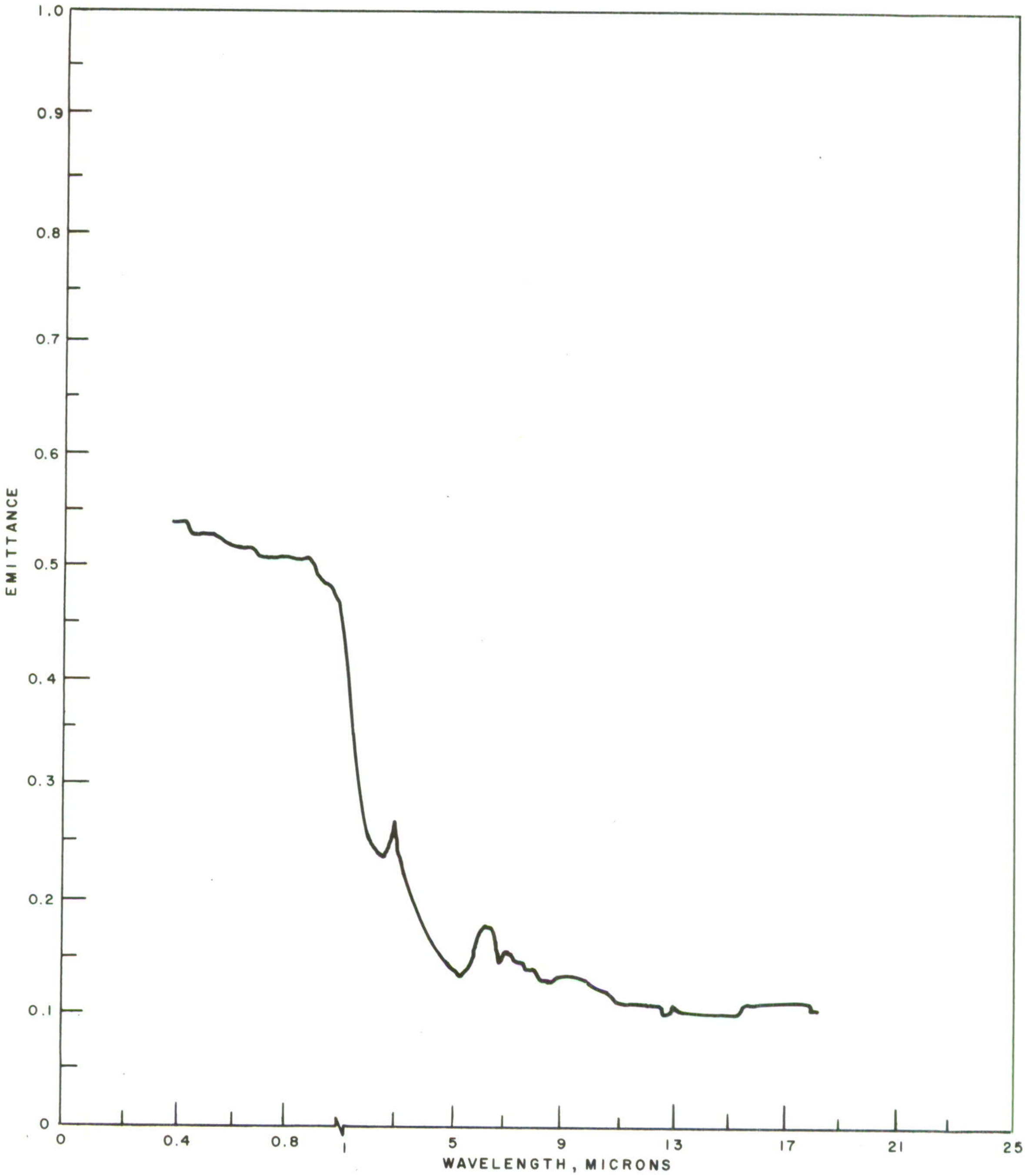

FIG. 47. Spectral Emittance of 2024-T3 Aluminum.

SPECTRAL EMITTANCE OF ANODIZED 6061-T6 ALUMINUM

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Gray chromic acid anodized; as received.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 23.

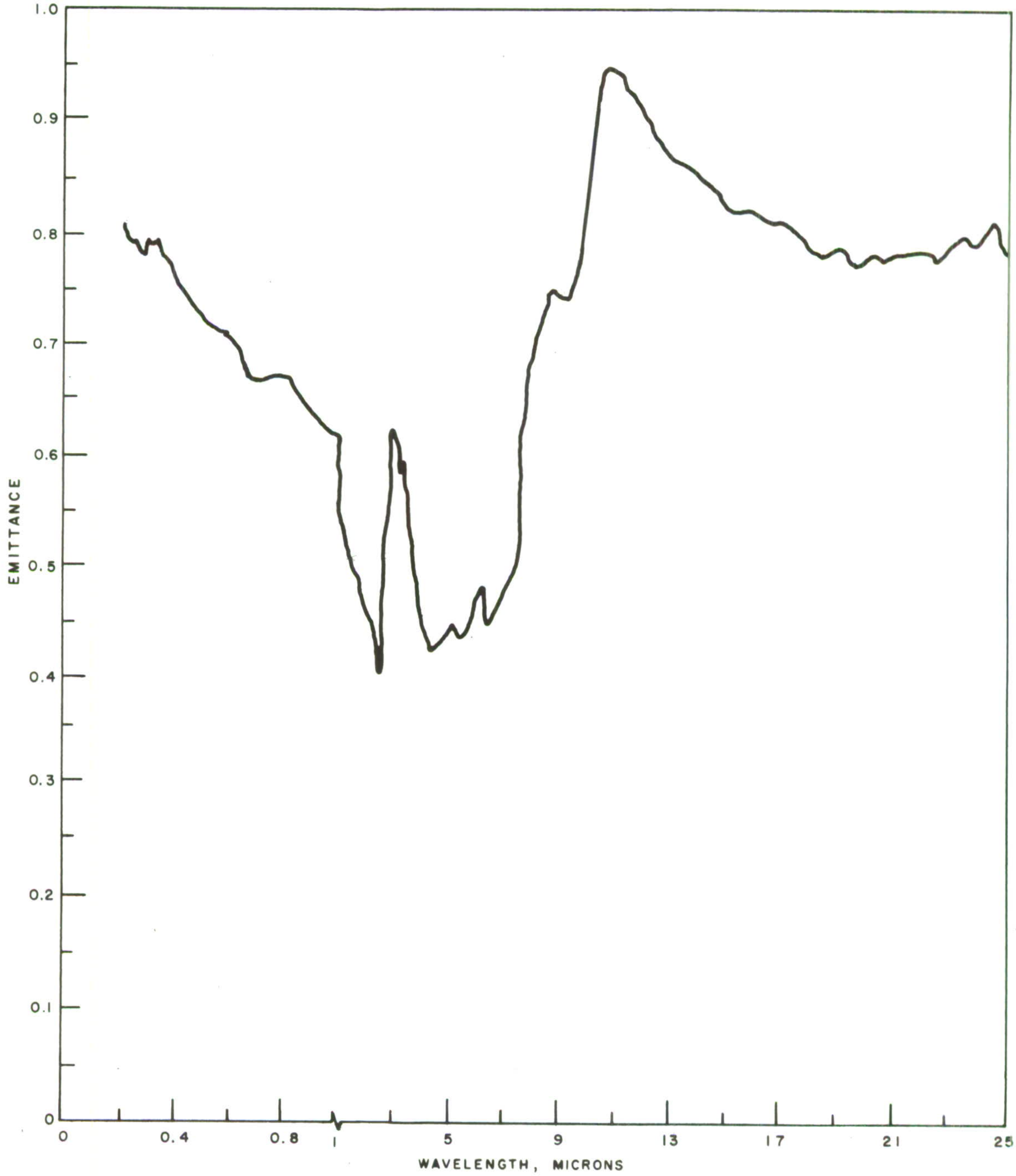

FIG. 48. Spectral Emittance of Anodized 6061-T6 Aluminum.

SPECTRAL EMITTANCE OF 1100-0 ALUMINUM

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Surface Conditions

As received, commercially pure aluminum.

Comments

Reflectance measurements in error by no more than 0.02 micron. Measurements were taken each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 22, p. 43.

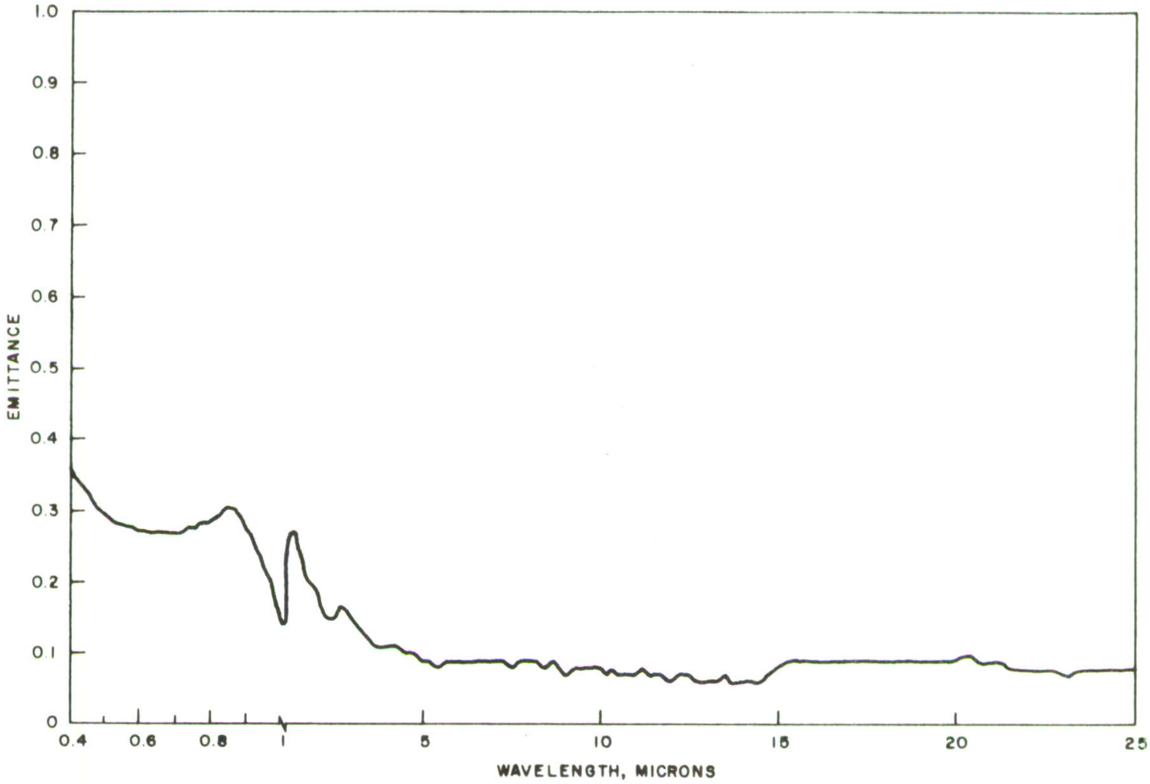

FIG. 49. Spectral Emittance of 1100-0 Aluminum.

SPECTRAL EMITTANCE OF POLISHED COPPER

Test Method

Reflectance measurements made using a hemispherical reflector with a Perkin-Elmer Model 112 spectrometer. A Golay detector was used.

Form of Original Data Presentation

Authors presented data as shown here.

Sample Temperature

295°K.

Surface Conditions

Polished and buffed to a high luster.

Comments

Data presented describes emittances at near-normal incidence (5 deg).

Source

Ref. 12, p. 5-23.

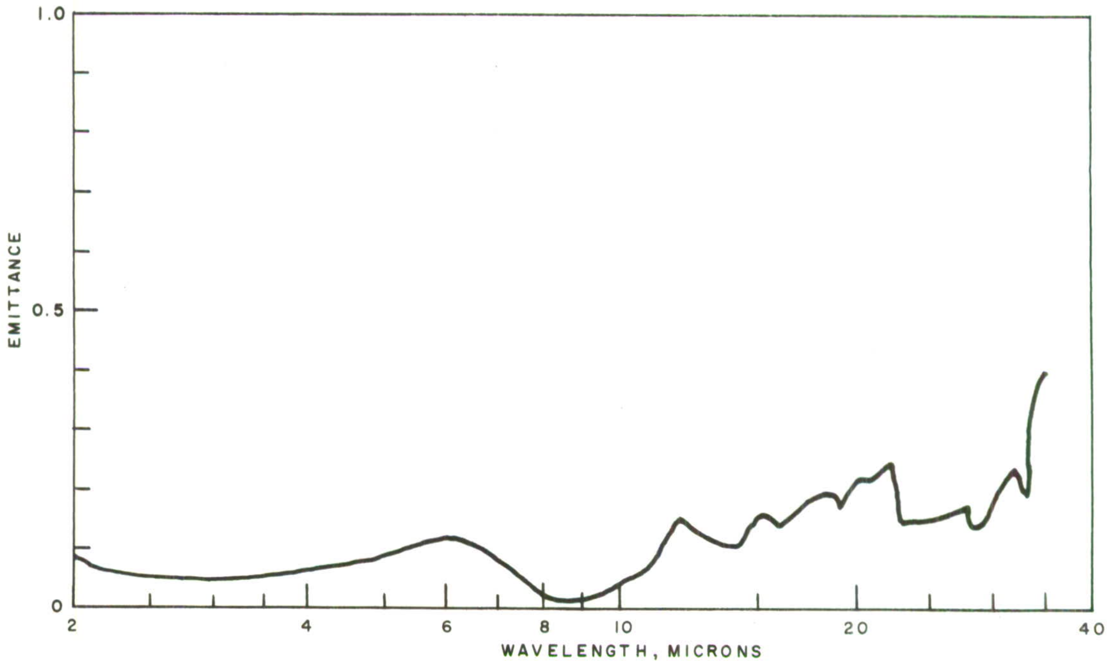

FIG. 50. Spectral Emittance of Polished Copper.

SPECTRAL EMITTANCE OF COPPER

Test Method

Absorptance measurements were made with a cavity reflectometer of the Gier-Dunkle type.

Form of Original Data Presentation

Author presented graph as shown here. (Other curves included on the same graph have been deleted.)

Sample Temperature

294°K.

Surface Conditions

Peak-to-peak surface roughness, 0.02 micron. Lateral surface roughness, 5.0 microns.

Comments

At wavelengths greater than 3 microns, determinations were made each 0.5 micron. The results shown are somewhat affected by deposits and oxidation, but this effect is minimal for the curve shown here.

Source

Ref. 32, p. 27.

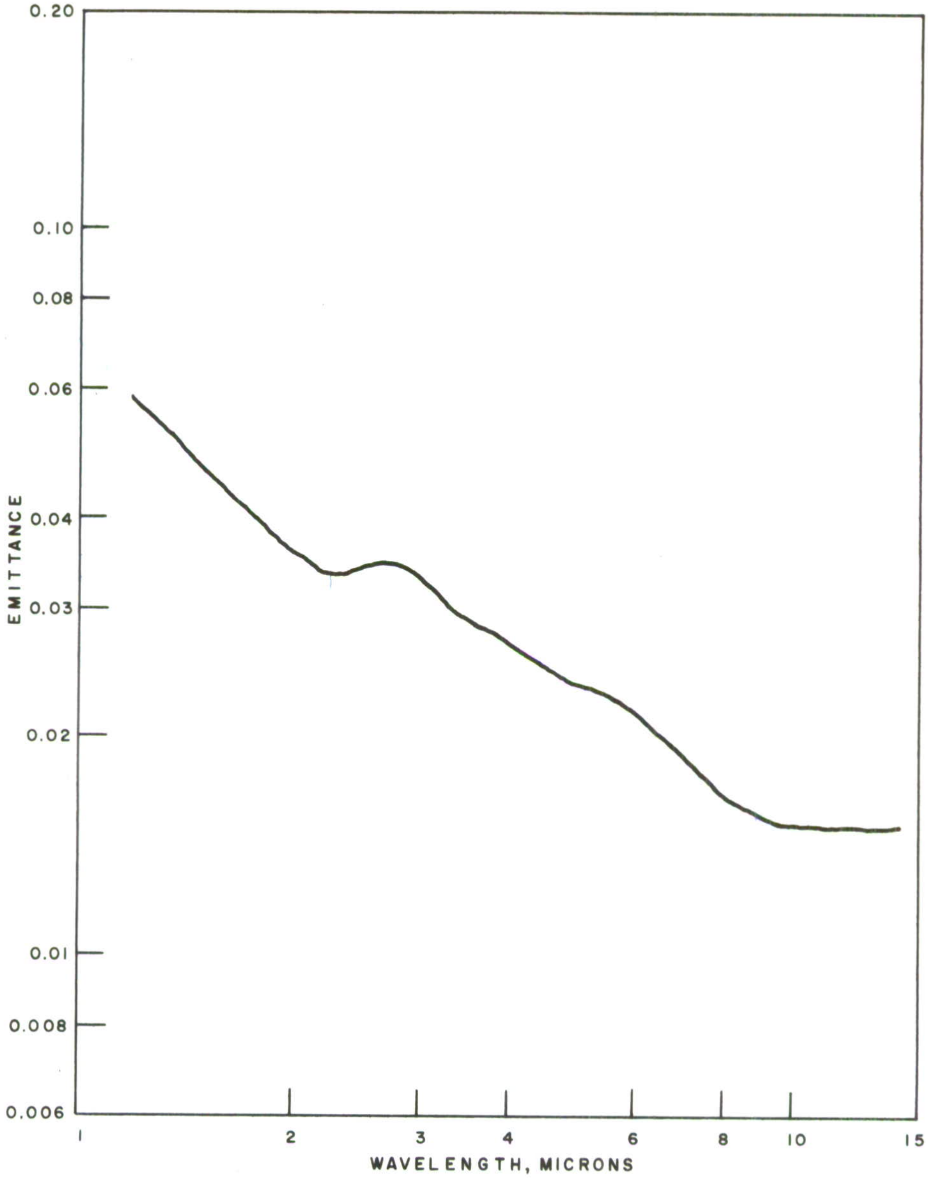

FIG. 51. Spectral Emittance of Copper.

SPECTRAL EMITTANCE OF NBS INCONEL

Test Method

Absorptance measurements made with a cavity reflectometer of the Gier-Dunkle type.

Form of Original Data Presentation

Author presented graph as shown here. (Other curves included on the same graph have been deleted.)

Sample Temperature

294°K.

Surface Conditions

Oxidized.

Comments

At wavelengths greater than 3 microns, determinations were made each 0.5 micron.

Source

Ref. 32, p. 43.

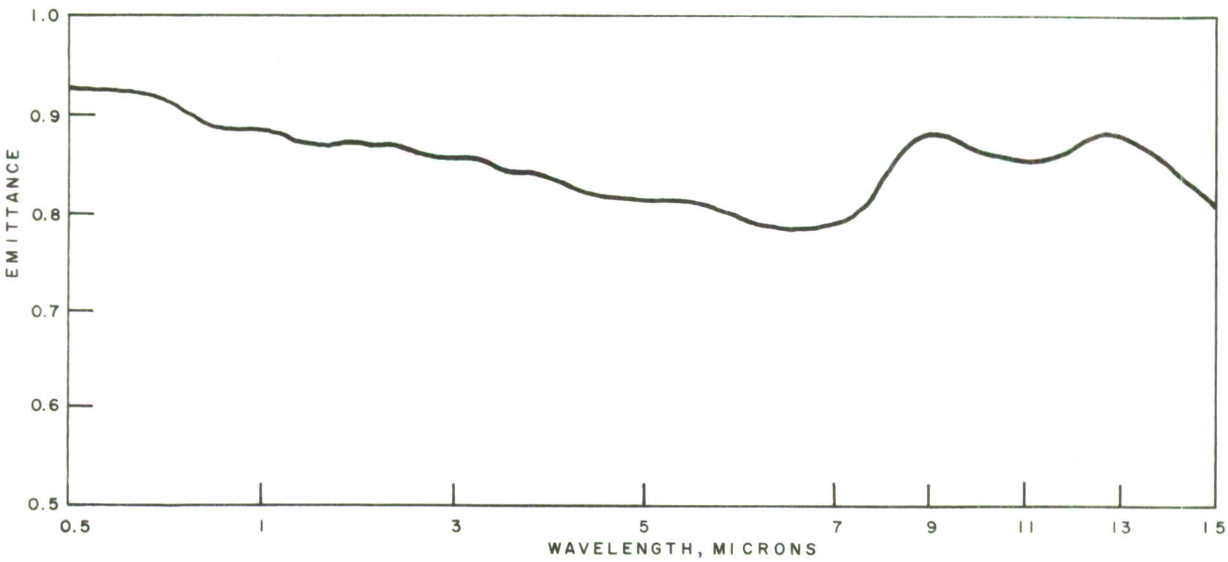

FIG. 52. Spectral Emittance of NBS Inconel.

SPECTRAL EMITTANCE OF IRON

Test Method

Absorptance measurements were made with a cavity reflectometer of the Gier-Dunkle type.

Form of Original Data Presentation

Author presented graph as shown here. (Other curves included on the same graph have been deleted.

Sample Temperature

294°K.

Surface Conditions

Pure iron sheet. Peak-to-peak roughness was 0.05 micron. The lateral roughness was 10 microns. Samples were polished with aluminum oxide and cleaned with water. All measurements were made as soon as possible after polishing to avoid all but minimum oxidation. When a relatively long time period was necessary, samples were kept in a low-humidity atmosphere.

Comments

At wavelengths greater than 3 microns, determinations were made each 0.5 micron.

Source

Ref. 32, p. 23.

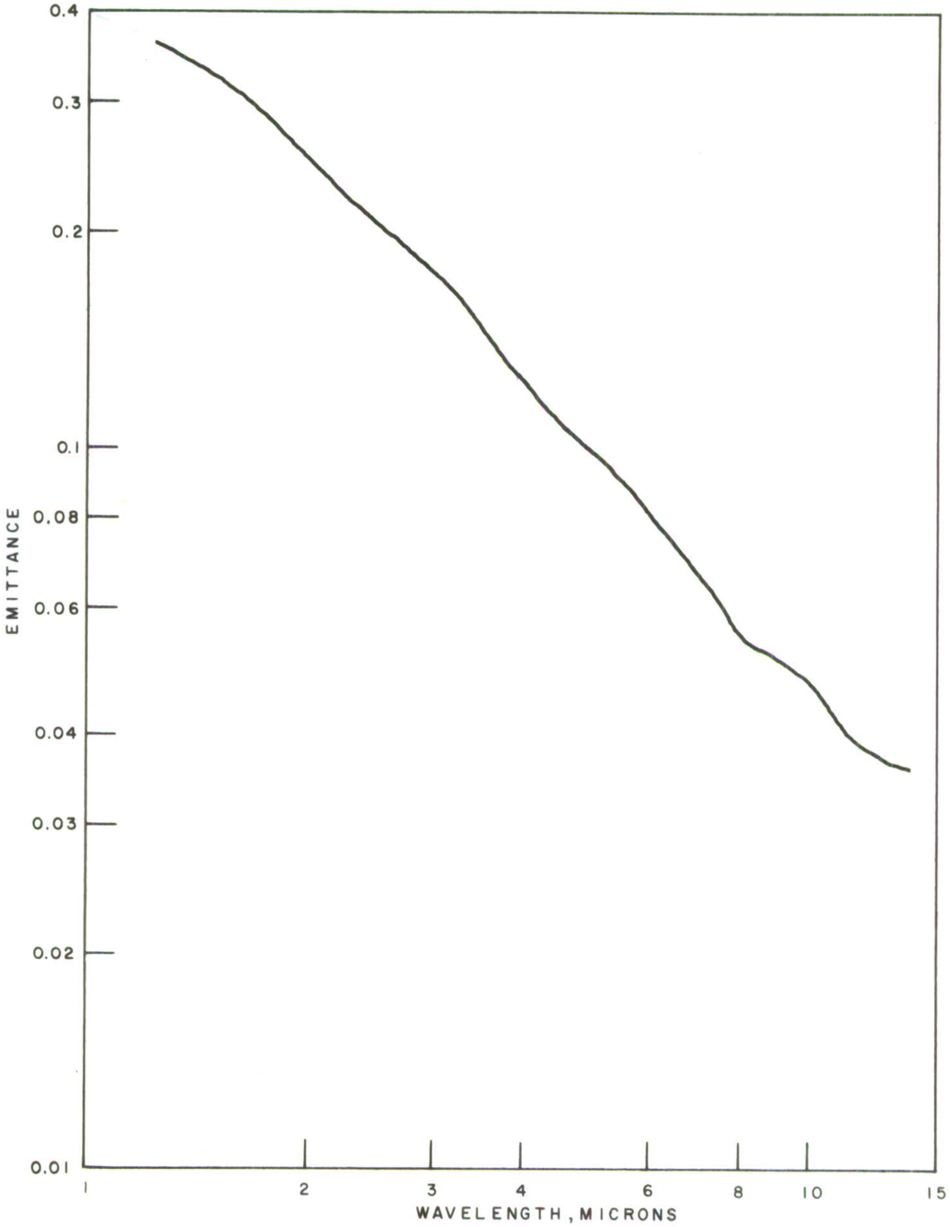

FIG. 53. Spectral Emittance of Iron.

SPECTRAL EMITTANCE OF AZ 31 MAGNESIUM

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Dow 17 treatment.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 16.

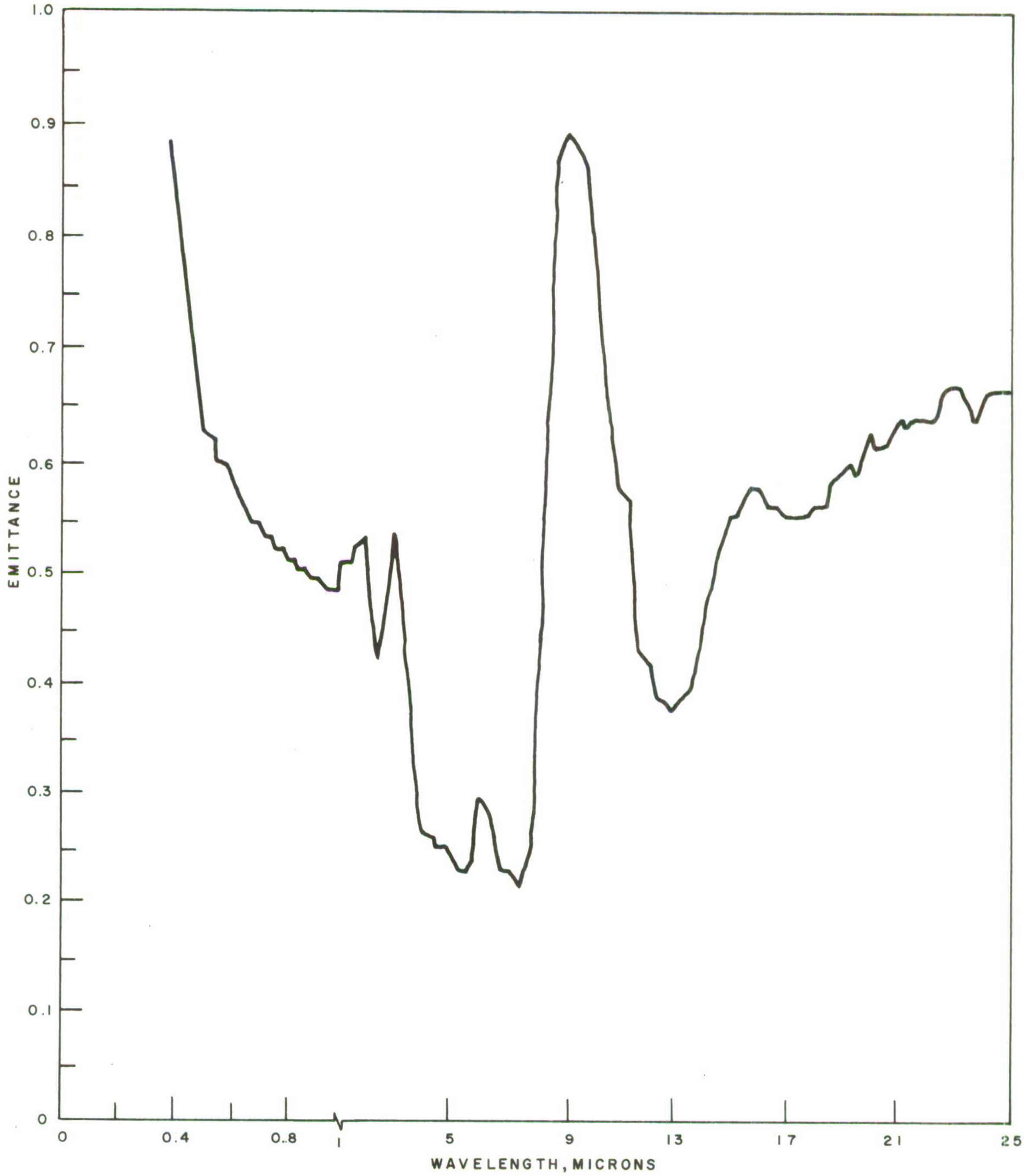

FIG. 54. Spectral Emittance of AZ 31 Magnesium.

SPECTRAL EMITTANCE OF A MAGNESIUM ALLOY

Test Method

Reflectance method used. Signal chopped for comparison with reference blackbody. Instrument used in 2.5- to 25-micron range was a model by Perkin-Elmer.

Form of Original Data Presentation

Author presented data as shown here.

Sample Temperature

323° ± 0.5°K.

Surface Conditions

Front surface of sample was roughened with a variety of emery papers, then brought to a fine polish with a grinding wheel and alumina powder. Average arithmetic roughness: 0.05 to 0.10 micron.

Comments

Magnesium surface acquired a cloudy appearance due to the formation of an oxide layer.

Source

Ref. 23, p. 51.

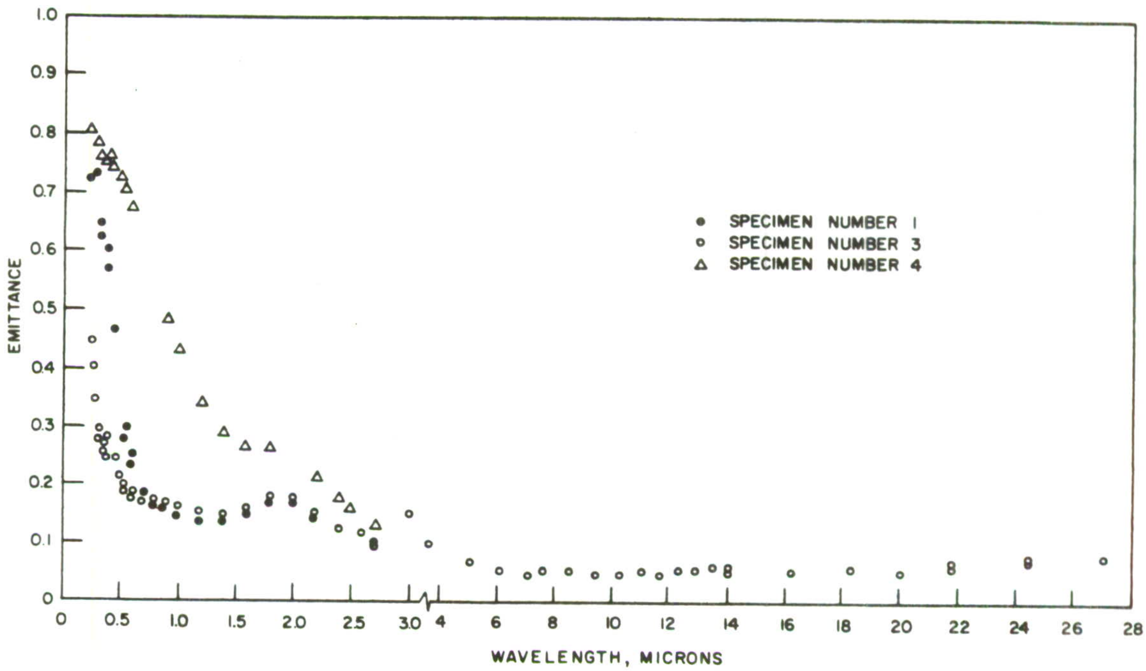

FIG. 55. Spectral Emittance of a Magnesium Alloy.

SPECTRAL EMITTANCE OF MOLYBDENUM

Test Method

Absorptance measurements made with a cavity reflectometer of the Gier-Dunkle type.

Form of Original Data Presentation

Author presented graph as shown. (Other curves included on the same graph have been deleted.)

Sample Temperature

294°K.

Surface Conditions

Sample cut from 0.005-inch-thick sheet. Peak-to-peak surface roughness, 0.25 micron.

Source

Ref. 32, p. 21.

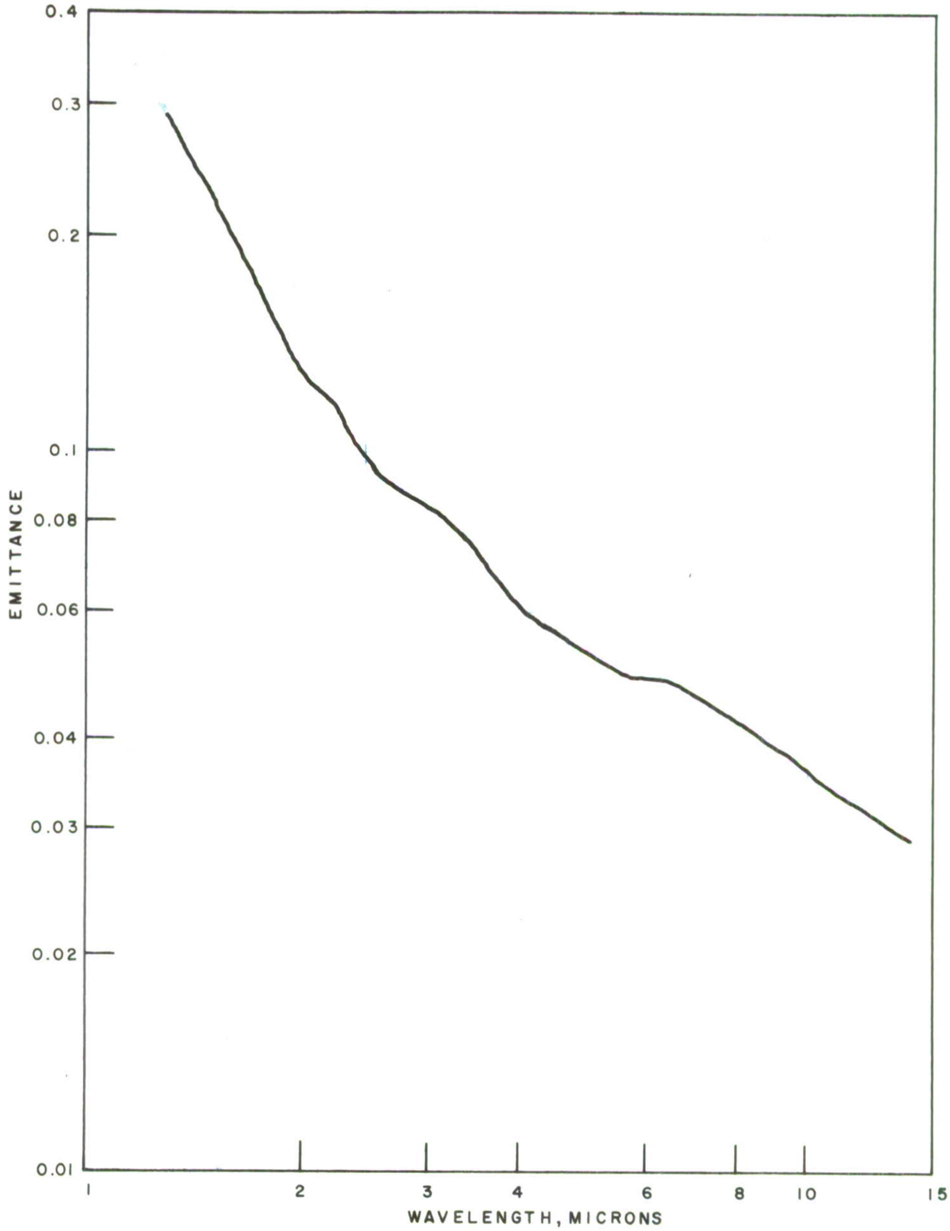

FIG. 56. Spectral Emittance of Molybdenum.

SPECTRAL EMITTANCE OF NICKEL

Test Method

Absorptance measurements made with a cavity reflectometer of the Gier-Dunkle type; reflectance readings made with Beckmann DK-2 spectroreflectometer; and roughness measurements with a Talysurf profilometer.

Form of Original Data Presentation

Author presented graph as shown here. (Other curves included on the same graph have been deleted.)

Sample Temperature

294°K.

Surface Conditions

Peak-to-peak surface roughness, 0.025 micron; 2.5 microns laterally (after mechanical polishing). Sample polished with aluminum oxide and cleaned with water.

Comments

This curve agrees well with the data for nine other samples (within 5%), but some other samples varied as much as 40%. Agreement with other sources is fairly good. The curve was obtained through absorptance measurements. At wavelengths greater than 3 microns, determinations were made each 0.5 micron.

Source

Ref. 32, p. 19.

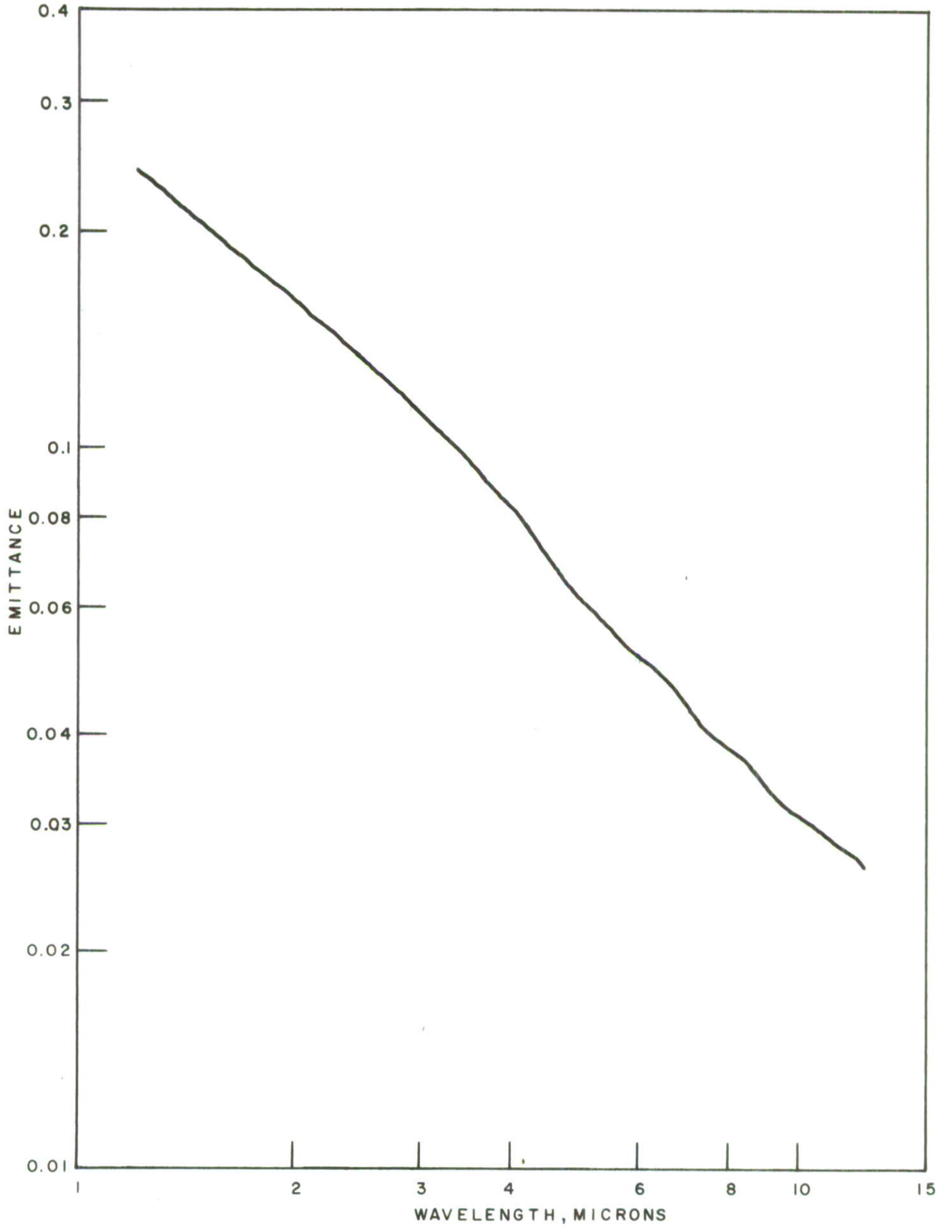

FIG. 57. Spectral Emittance of Nickel.

SPECTRAL EMITTANCE OF TYPE 316 STAINLESS STEEL

Test Method

Reflectance method used. Signal chopped to compare with reference blackbody. Range 0.25 to 25 microns monitored with a Perkin-Elmer instrument.

Form of Original Data Presentation

Author presented data as shown here.

Sample Temperature

323° ± 0.5°K.

Surface Conditions

Electropolished with a solution of orthophosphoric acid, glycerine, and water. Average arithmetic roughness: 0.01 to 0.04 micron.

Comments

Type 304 stainless steel has similar spectral emittance.

Source

Ref. 23, p. 45.

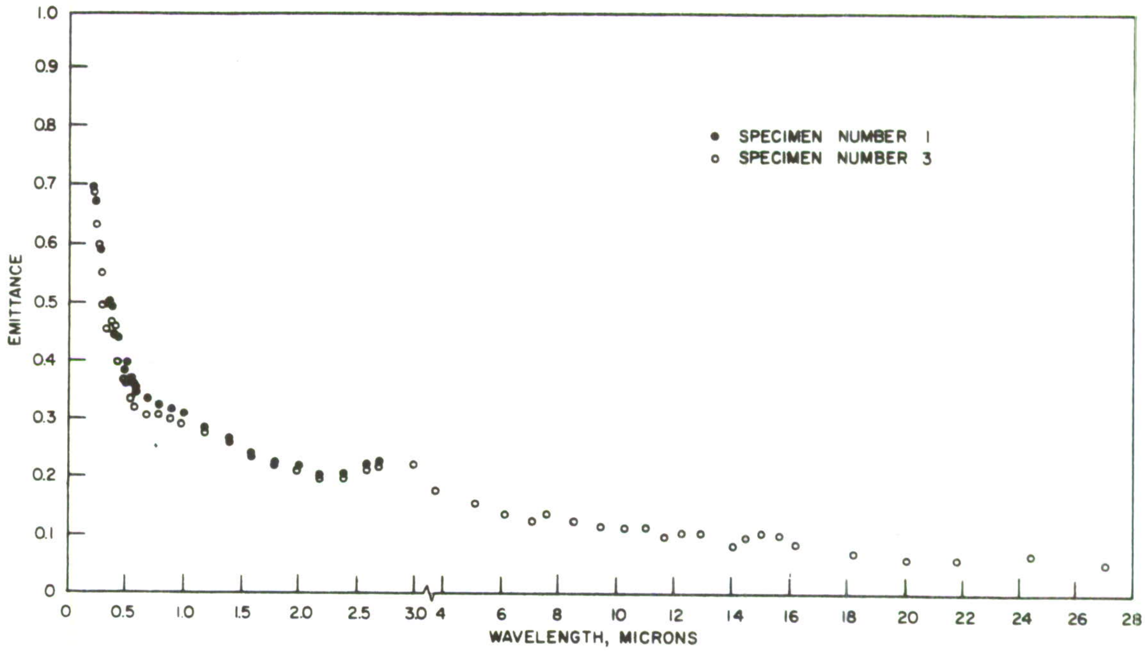

FIG. 58. Spectral Emittance of Type 316 Stainless Steel.

SPECTRAL EMITTANCE OF TYPE 321 STEEL

Test Method

Gier-Dunkle cavity radiator was used in conjunction with a Perkin-Elmer Model 83 monochromator.

Form of Original Data Presentation

Graph of reflectance versus wavelength.

Sample Temperature

Approximately 339°K.

Source

Ref. 3, p. 1408.

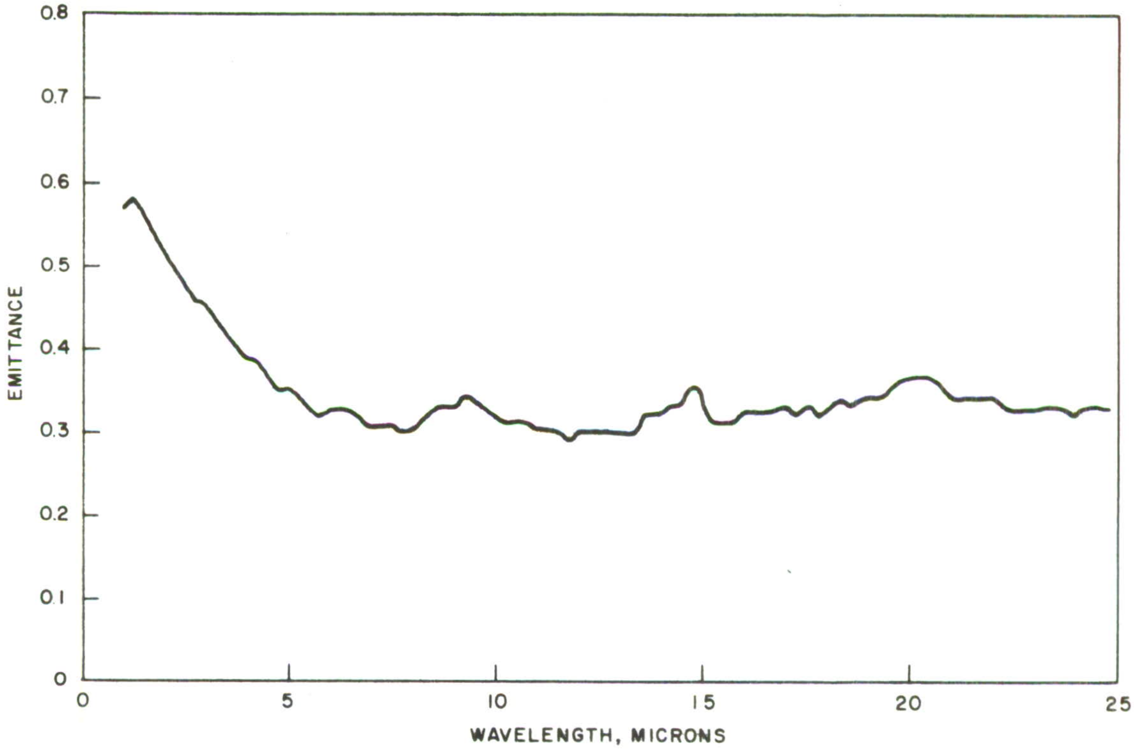

FIG. 59. Spectral Emittance of Type 321 Steel.

SPECTRAL EMITTANCE OF TYPE 321 CORROSION RESISTANT STEEL

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Comments

Reflectance measurements were in error by no more than 0.02. Measurements were taken each 0.25 micron between 1.0 and 25.0 microns. Compare Fig. 60 with Fig. 59.

Source

Ref. 22, p. 70.

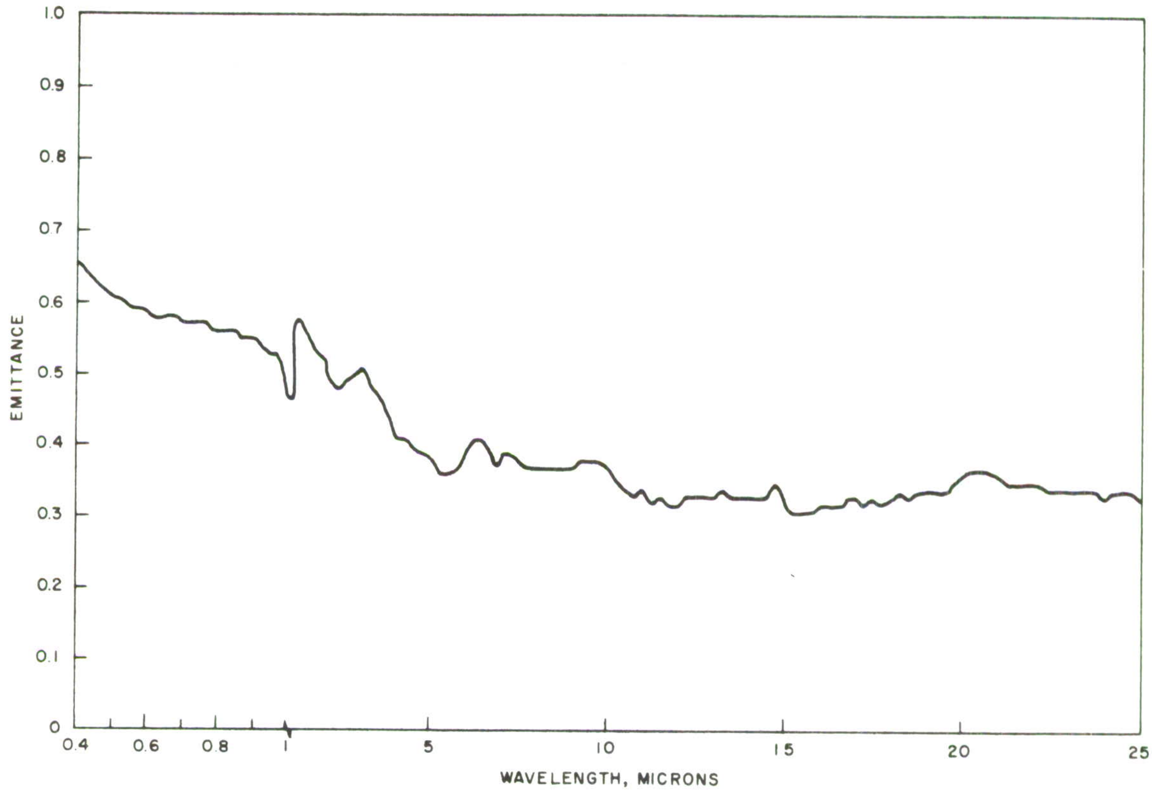

FIG. 60. Spectral Emittance of Type 321 Corrosion Resistant Steel.

SPECTRAL EMITTANCE OF AM 350 STEEL

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Comments

Reflectance measurements are in error by no more than 0.02. Measurements were taken each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 22, p. 66.

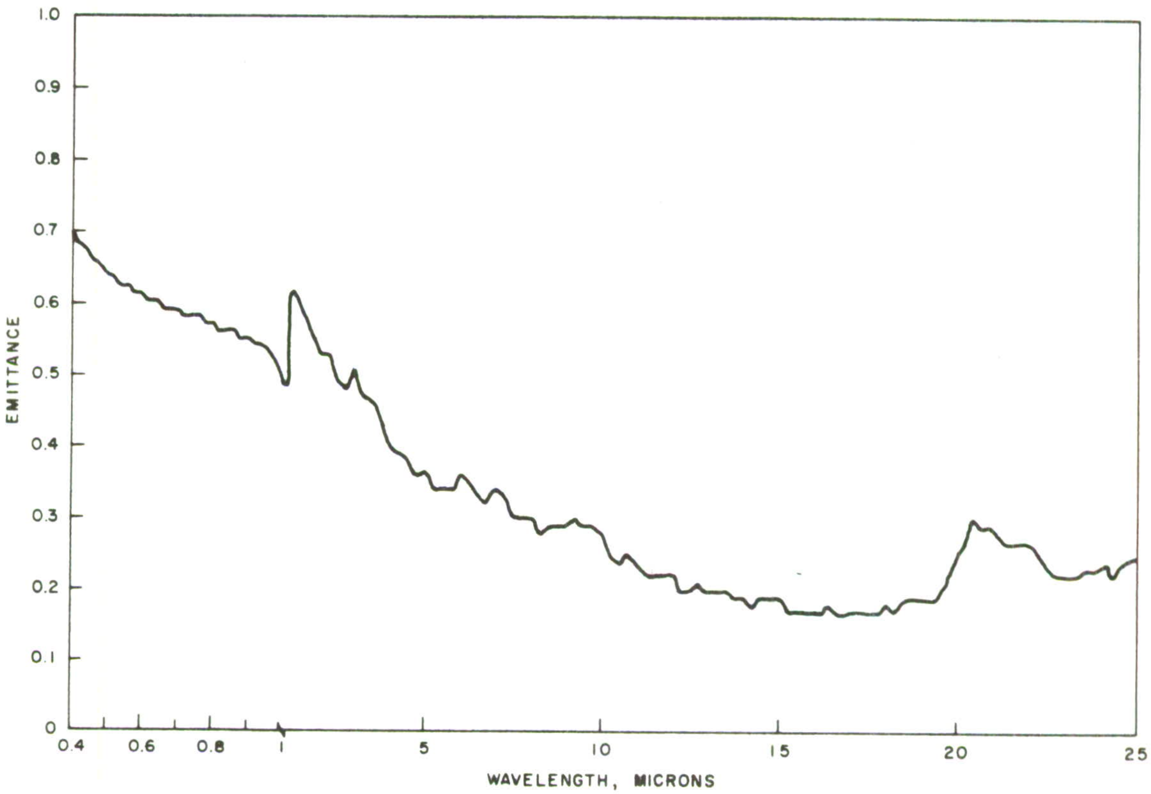

FIG. 61. Spectral Emittance of AM 350 Steel.

SPECTRAL EMITTANCE OF 410 STAINLESS STEEL

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 7.

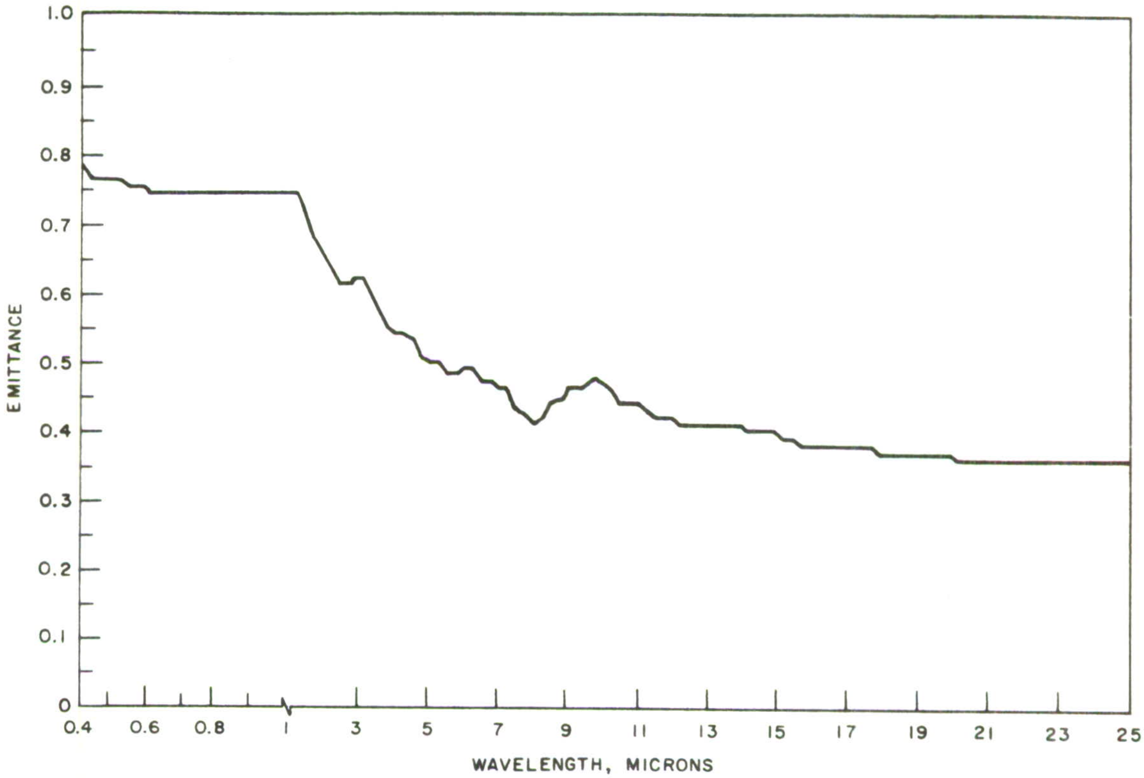

FIG. 62. Spectral Emittance of 410 Stainless Steel.

SPECTRAL EMITTANCE OF SANDBLASTED 410 STAINLESS STEEL

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Fine sandblasted. This was done at Cooper Development Corp., Monrovia, California, using 100-mesh grit with the nozzle held 12 inches from the part. When all surfaces were completely abraded, the run was considered complete.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 9.

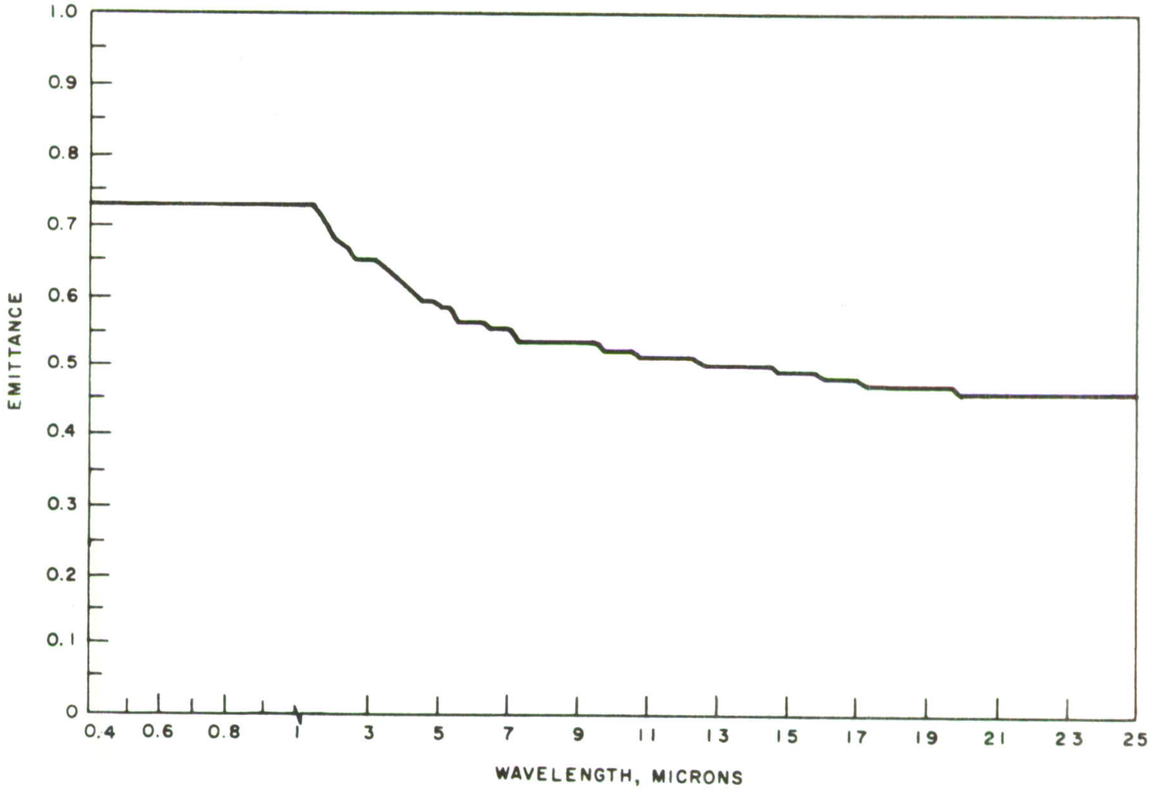

FIG. 63. Spectral Emittance of Sandblasted 410 Stainless Steel.

SPECTRAL EMITTANCE OF ETCHED 430 STAINLESS STEEL

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Etchant used was Aqua Regia (3 parts HCl, 1 part HNO_3). Samples were swabbed with etchant for about 5 seconds, rinsed in hot water, and subjected to a dry-air blast to avoid staining.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 9.

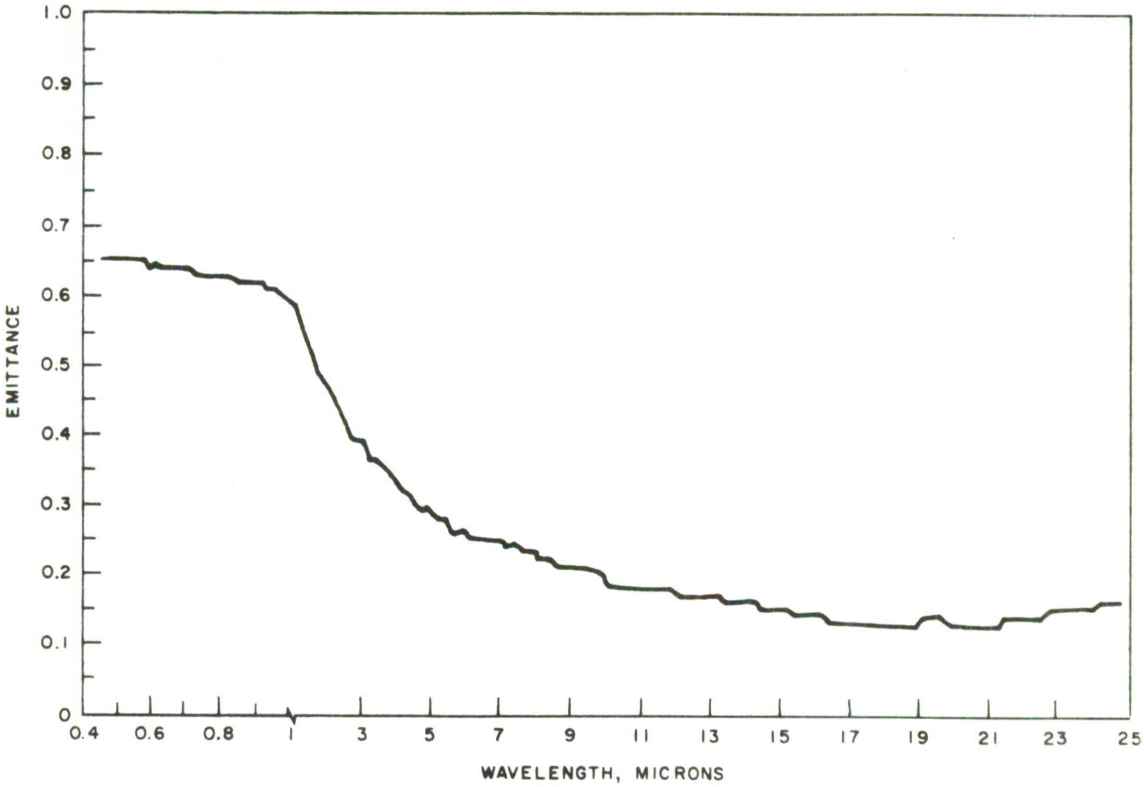

FIG. 64. Spectral Emittance of Etched 430 Stainless Steel.

SPECTRAL EMITTANCE OF TI-75A TITANIUM

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Surface Conditions

As received, commercially pure.

Comments

Reflectance measurements are in error by no more than 0.02. Measurements were taken each 0.25 micron between 11.0 and 25.0 microns.

Source

Ref. 22, p. 57.

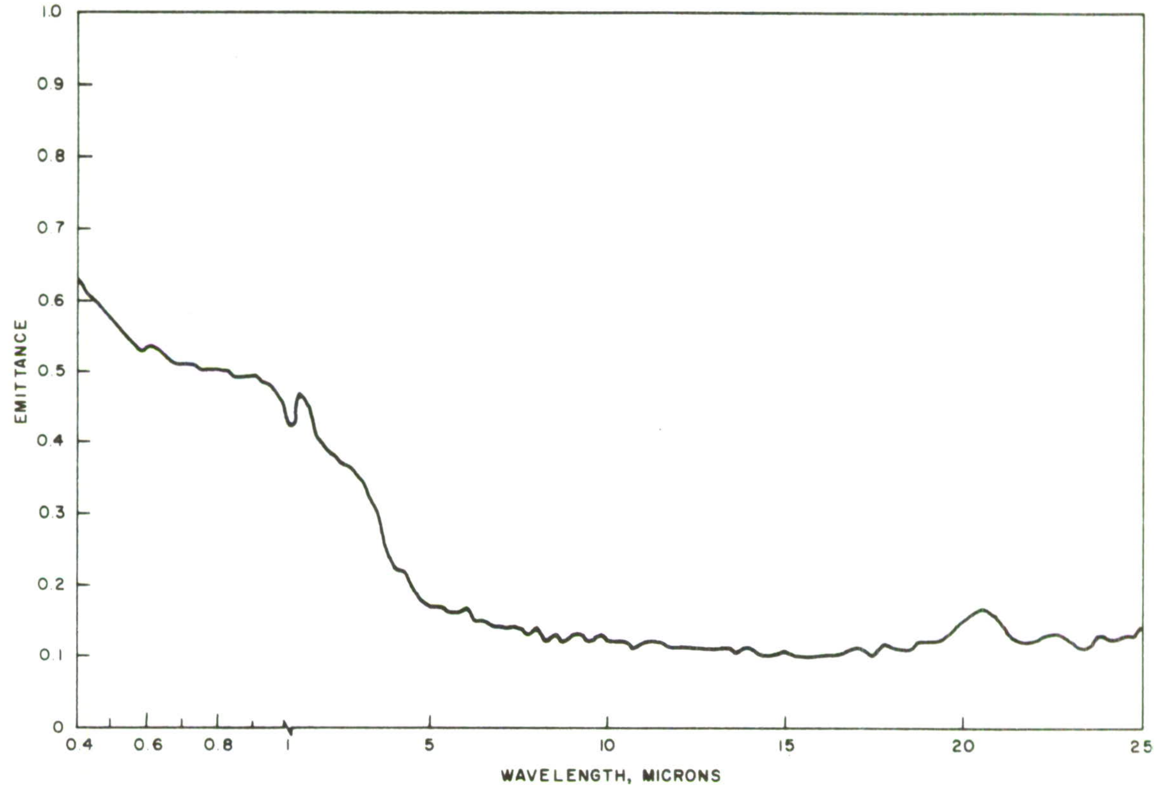

FIG. 65. Spectral Emittance of Ti-75A Titanium.

SPECTRAL EMITTANCE OF C-110M TITANIUM ALLOY

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Comments

Reflectance measurements are in error by no more than 0.02. Measurements were taken each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 22, p. 63.

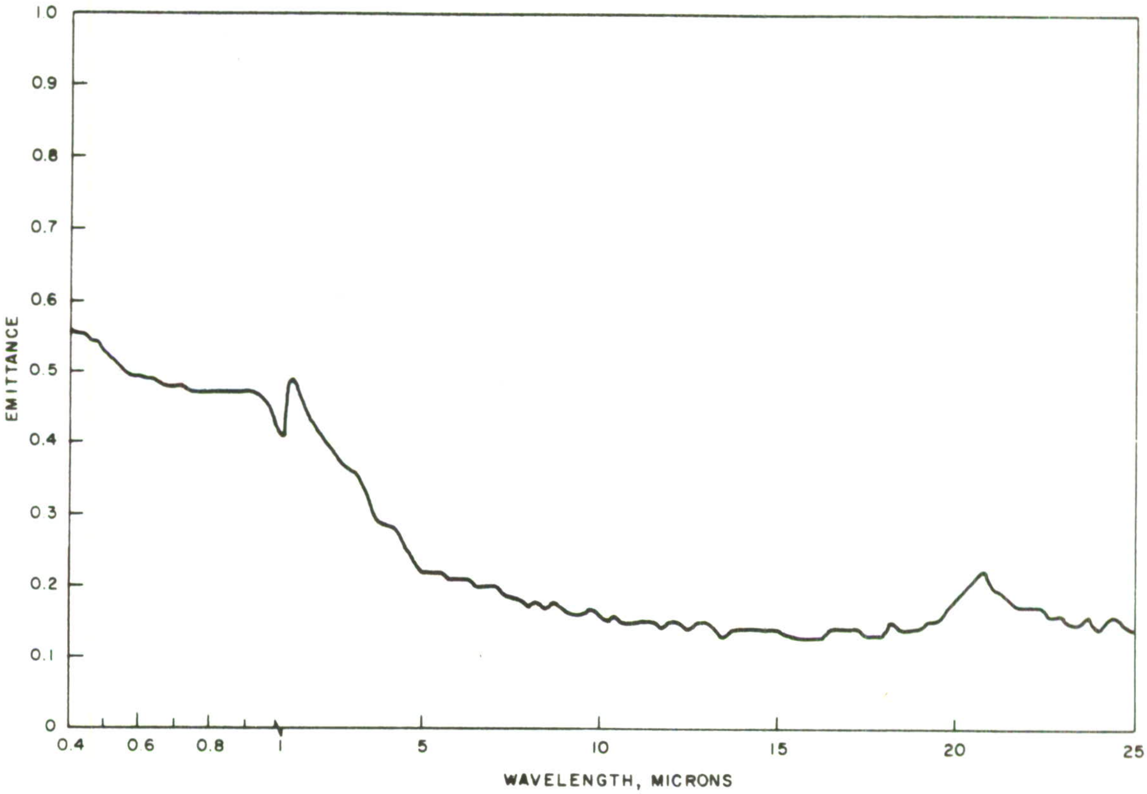

FIG. 66. Spectral Emittance of C-110M Titanium Alloy.

NORMAL SPECTRAL EMITTANCE OF REMINGTON TITANIUM

Test Method

Emissivity was calculated from reflectance data obtained with a Perkin-Elmer Model 13 monochromator as a dispersing and detecting system with an auxiliary system of optics.

Form of Original Data Presentation

Authors presented data as shown here.

Sample Temperature

304°K.

Source

Ref. 15, App. 11.

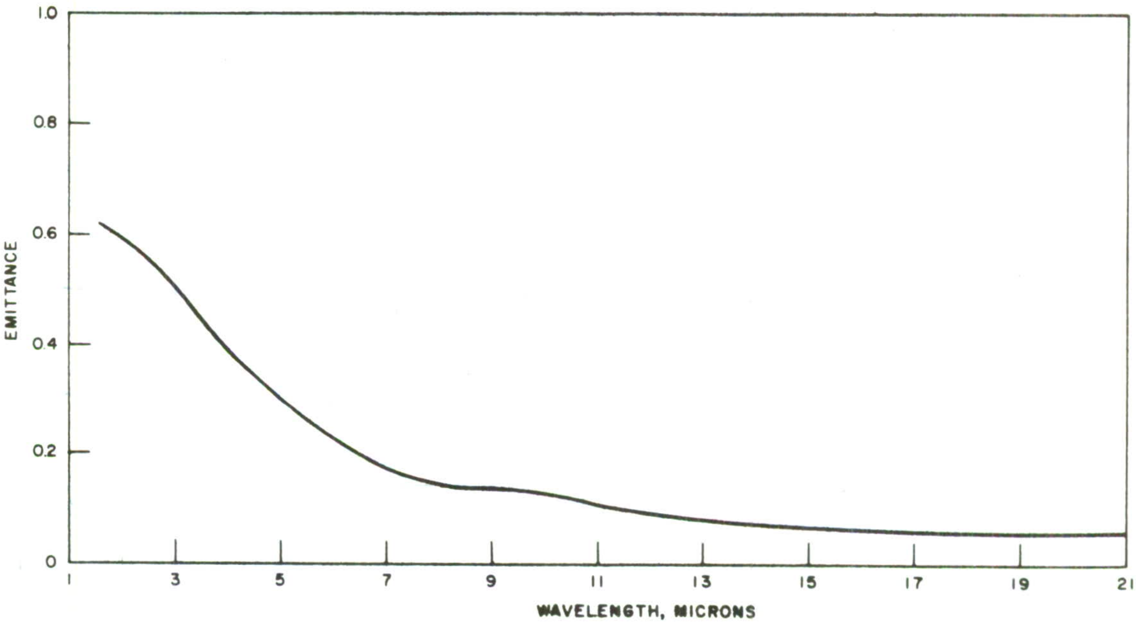

FIG. 67. Normal Spectral Emittance of Remington Titanium.

SPECTRAL EMITTANCE OF GAL-4V TITANIUM ALLOY

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

125 finish.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 13.

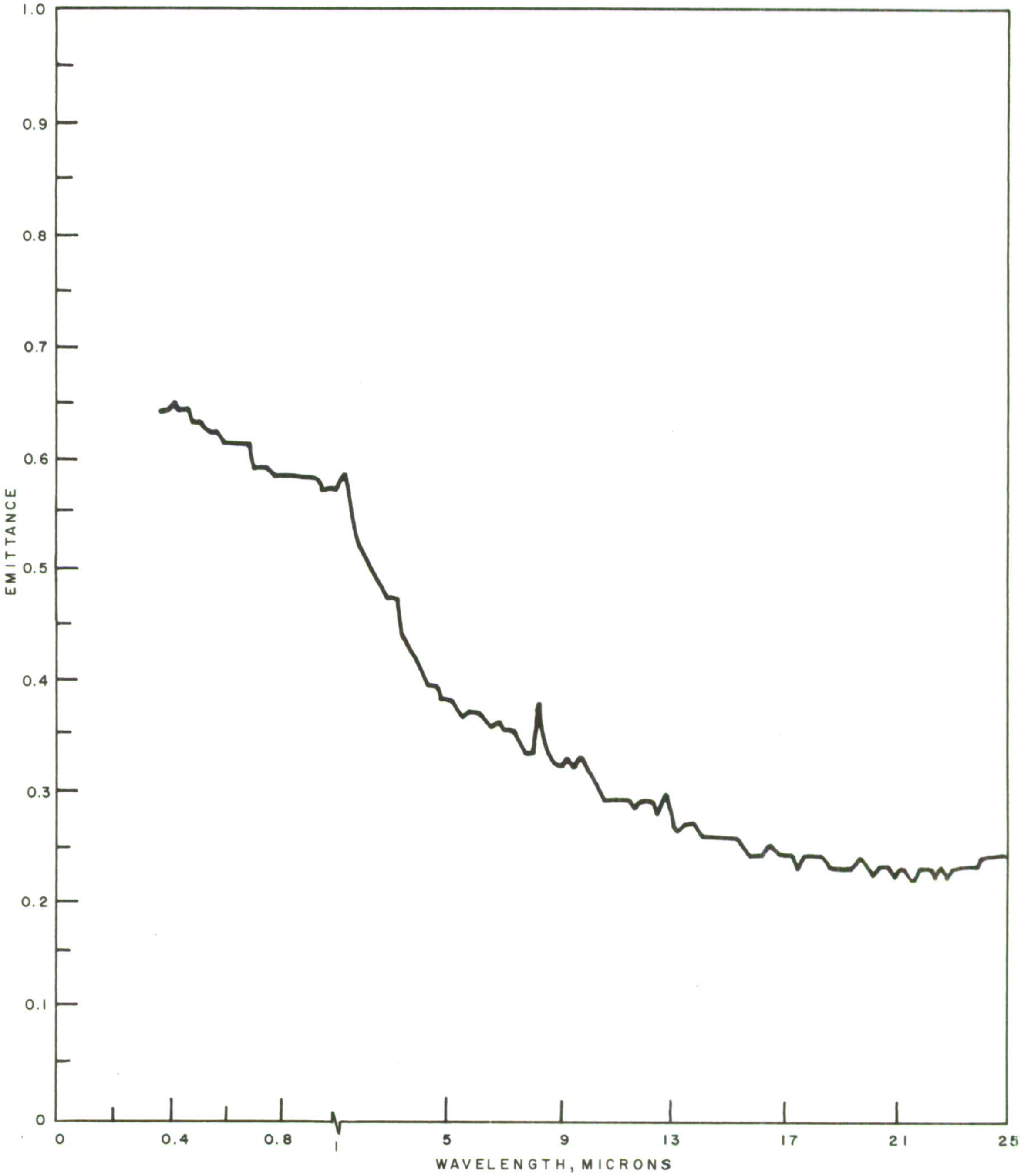

FIG. 68. Spectral Emittance of GAL-4V Titanium Alloy.

SPECTRAL EMITTANCE OF ANODIZED TITANIUM ON STAINLESS STEEL

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Comments

Reflectance measurements are in error by no more than 0.02. Measurements were taken each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 22, p. 117.

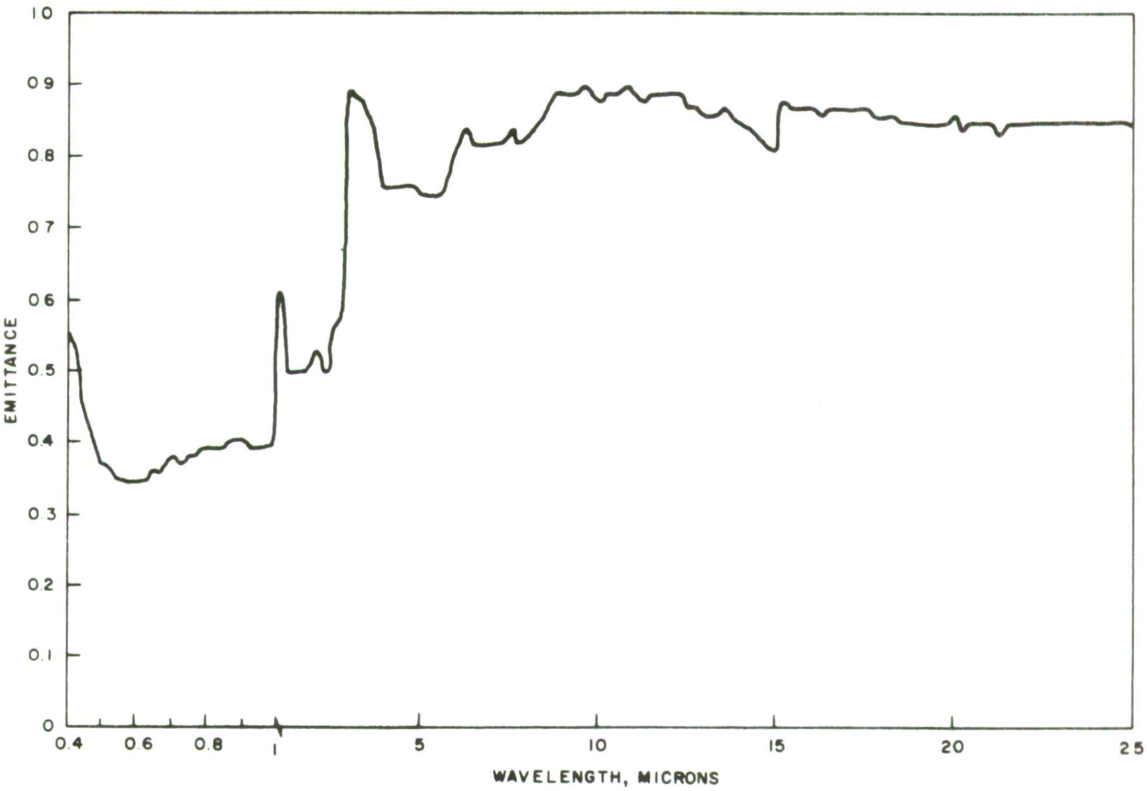

FIG. 69. Spectral Emittance of Anodized Titanium on Stainless Steel.

EMITTANCE OF PAINT COATINGS

It is evident from the two graphs showing the spectral emittance of aluminized silicone paint on steel (Fig. 70) and on titanium (Fig. 71), and from the information for emittance of the same steel (Fig. 60) and titanium (Fig. 65), that the paint coating has changed the level of emittance of the surface area upon which it was painted. This change amounts to 5- to 10-percent change in level, in different directions for the two samples in the 8- to 14-micron region. The paint coating has also changed the character of the emittance curve. The paints measured appear to have rather high emittance, especially in the 8- to 14-micron region, with the exception of the aluminum and silicone paints, which have low emittances over most of the wavelength interval presented.

Considerable data exists, and is presently being generated, on the subject of the reflectance of various paints on different substrates (Ref. 28). The graphs included in this report are a small example of the available data but provide representative information.

SPECTRAL EMITTANCE OF ALUMINIZED SILICONE PAINT (321 STEEL BACKING)

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Surface Conditions

Dow Corning XP-310 Aluminized Silicone Paint on Type 321 Corrosion Resistant Steel (0.001-inch thickness of paint).

Comments

Reflectance measurements are in error by no more than 0.02. Measurements were taken each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 22, p. 46.

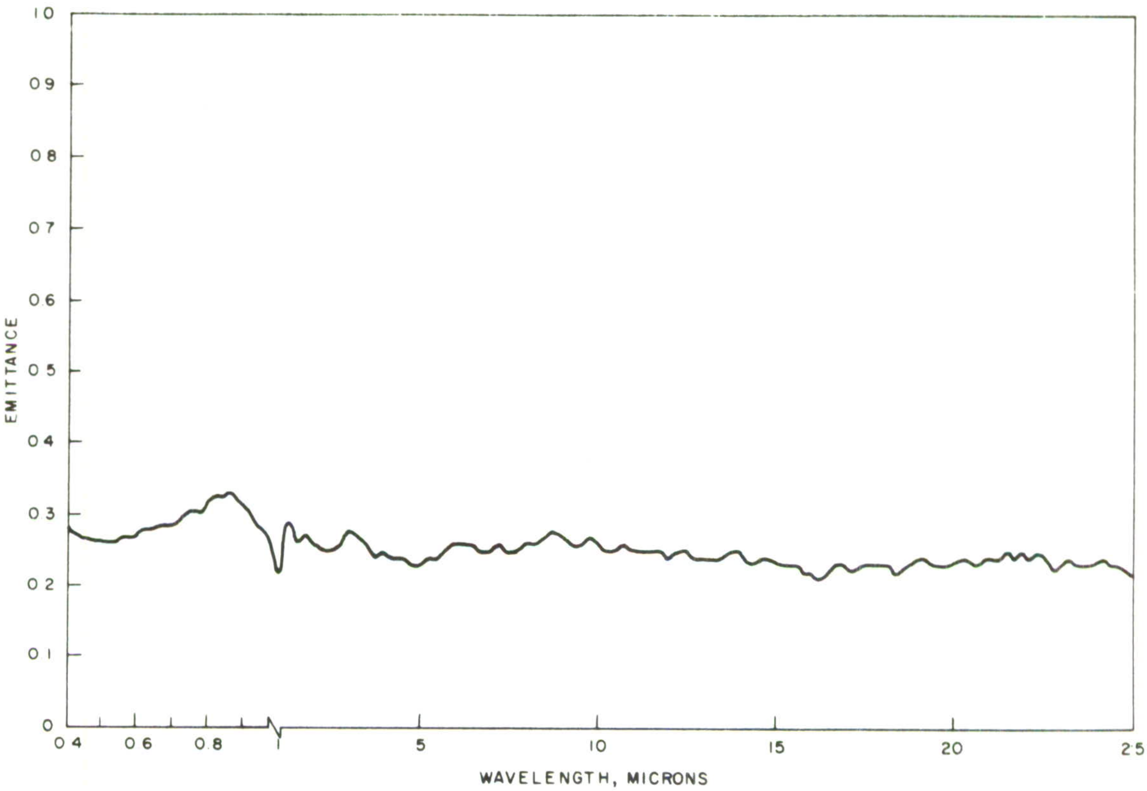

FIG. 70. Spectral Emittance of Aluminized Silicone Paint (321 Steel Backing).

SPECTRAL EMITTANCE OF ALUMINIZED SILICONE PAINT (TITANIUM BACKING)

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Surface Conditions

Dow Corning XP-310 Aluminized Silicone Paint on Ti-75A Titanium (0.001-inch thickness of paint). 25.4μ

Comments

Reflectance measurements are in error by no more than 0.02. Measurements were taken each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 22, p. 51.

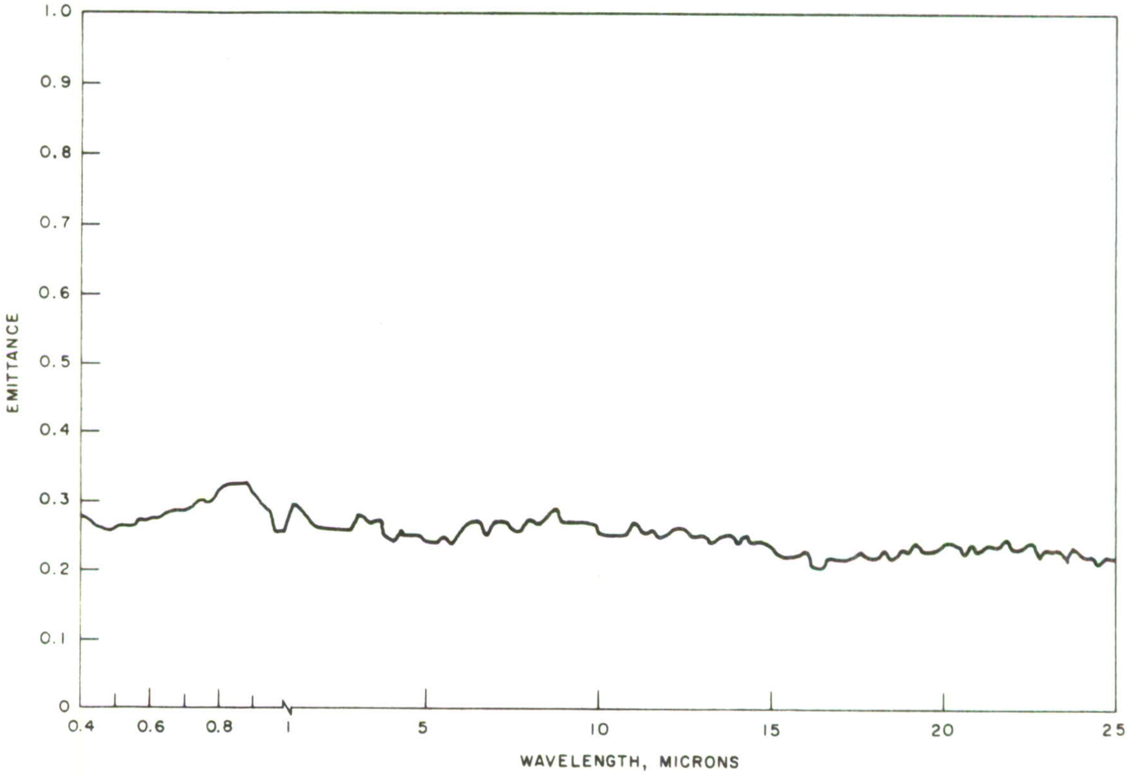

FIG. 71. Spectral Emittance of Aluminized Silicone Paint (Titanium Backing).

SPECTRAL EMITTANCE OF DUTCH BOY ALUMINUM PAINT

Test Method

Heated cavity reflectometer used in conjunction with a Perkin-Elmer spectrometer.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Dutch Boy Quick Drying Enamel painted on a copper cylinder.

Comments

Emissivity of copper is small at wavelengths greater than 5 microns. Data presented are conservatively stated to be accurate to within 5 percent.

Source

Ref. 29, Curve 13.

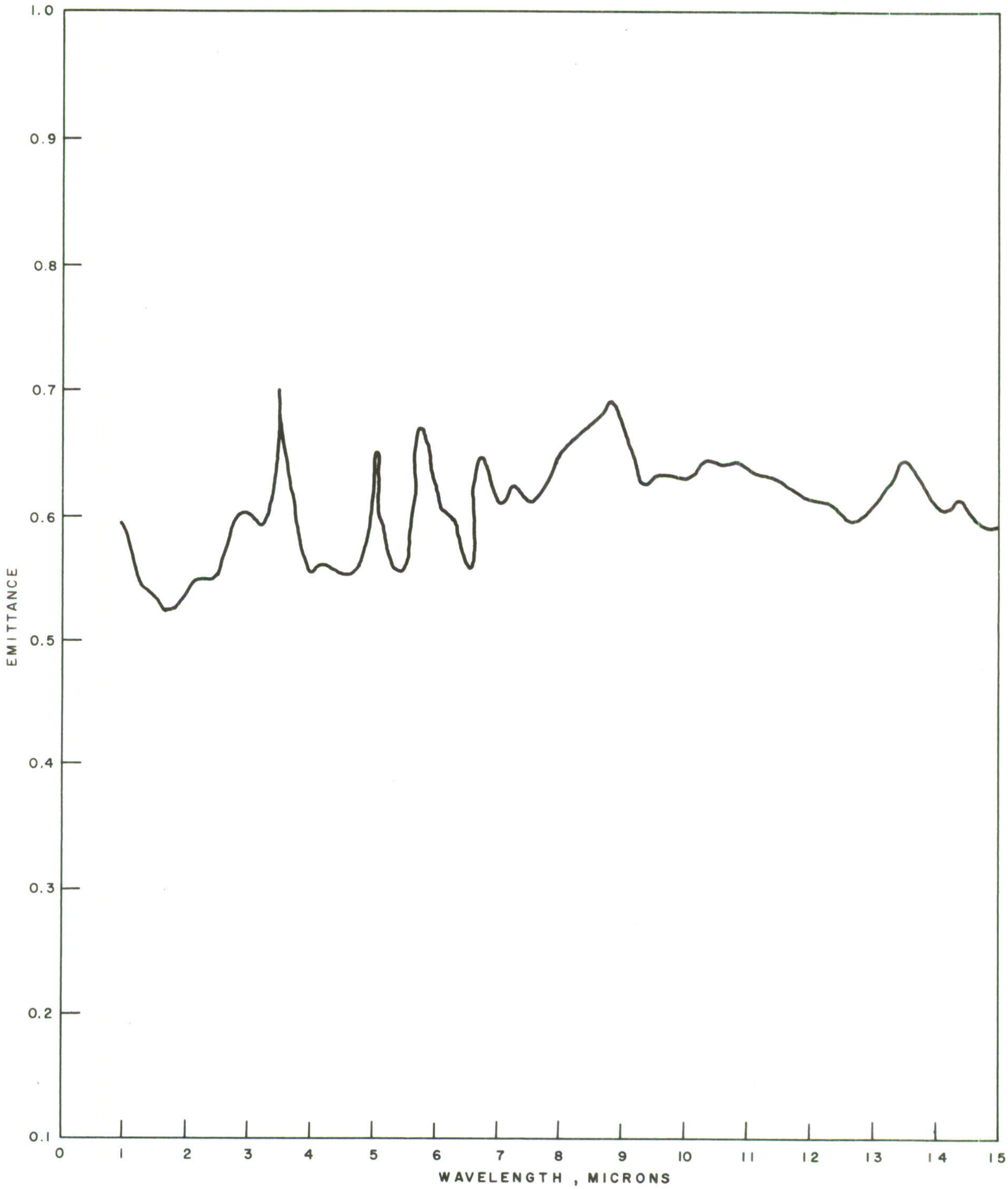

FIG. 72. Spectral Emittance of Dutch Boy Aluminum Paint.

SPECTRAL EMITTANCE OF KERPO ALUMINUM PAINT (6061-T6 ALUMINUM BACKING)

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Two coats No. 25 Aluminum Kerpo spray paint on 6061-T6 aluminum backing.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 22.

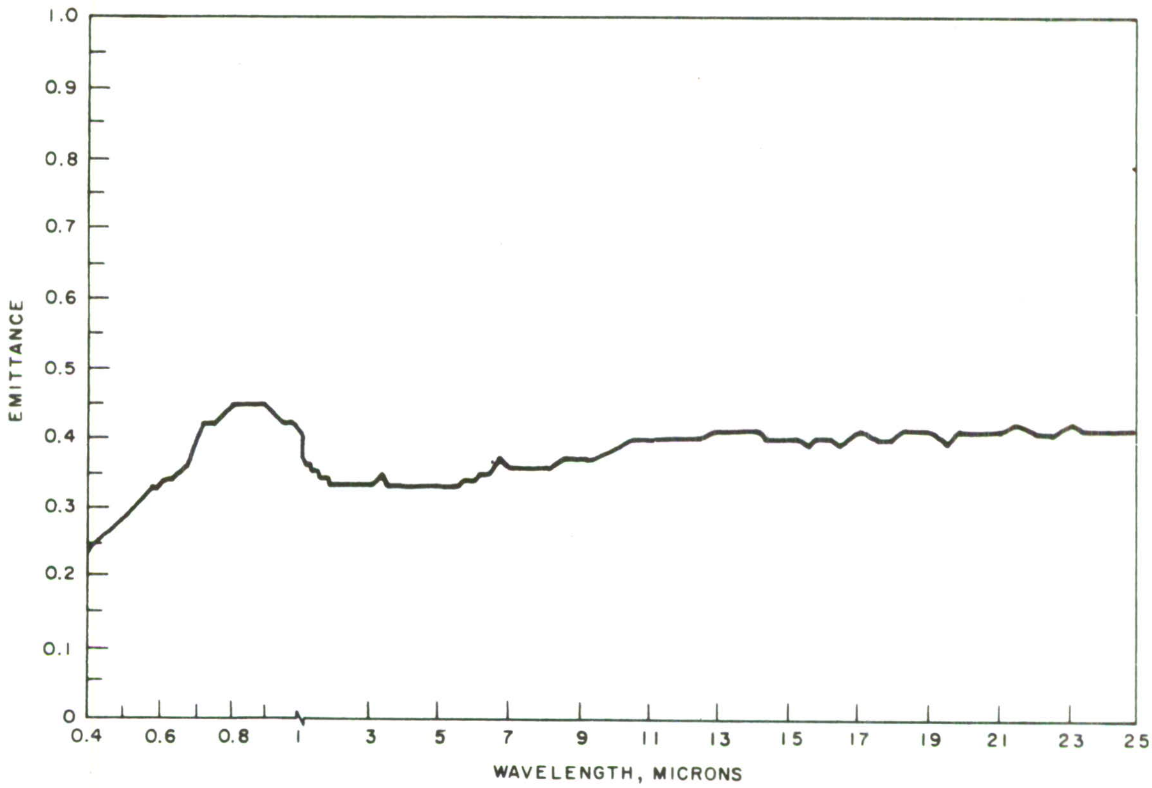

FIG. 73. Spectral Emittance of Kerpo Aluminum Paint (6061-T6 Aluminum Backing).

SPECTRAL EMITTANCE OF FULLER BLACK PAINT

Test Method

Reflectance measurements made using a hemispherical reflector with a Perkin-Elmer Model 112 spectrometer. A Golay detector was used.

Form of Original Data Presentation

Authors presented data as shown here.

Sample Temperature

295°K.

Surface Conditions

Fuller Gloss Black Paint (518-B-2) sprayed directly on an aluminum substrate (assumed to have been mill finished). Paint thickness, 0.007 inch. 178 μ

Source

Ref. 12, pp. 5–9.

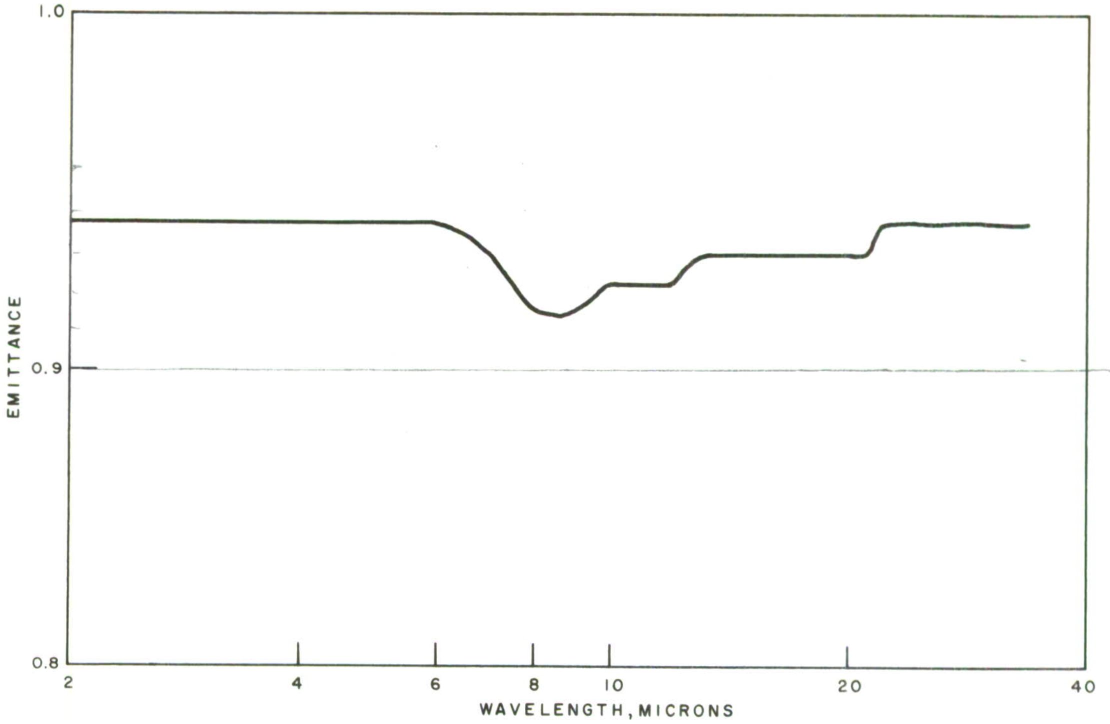

FIG. 74. Spectral Emittance of Fuller Black Paint.

SPECTRAL EMITTANCE OF GLIDDEN BLACK ENAMEL

Test Method

Heated cavity reflectometer used in conjunction with a Perkin-Elmer spectrometer.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Glidden Japalac Quick Drying Enamel, 1207 Brilliant Black, painted on a copper cylinder.

Comments

Emissivity of copper is small at wavelengths greater than 5 microns. Data presented are conservatively stated to be accurate to within 5%.

Source

Ref. 29, Curve 16.

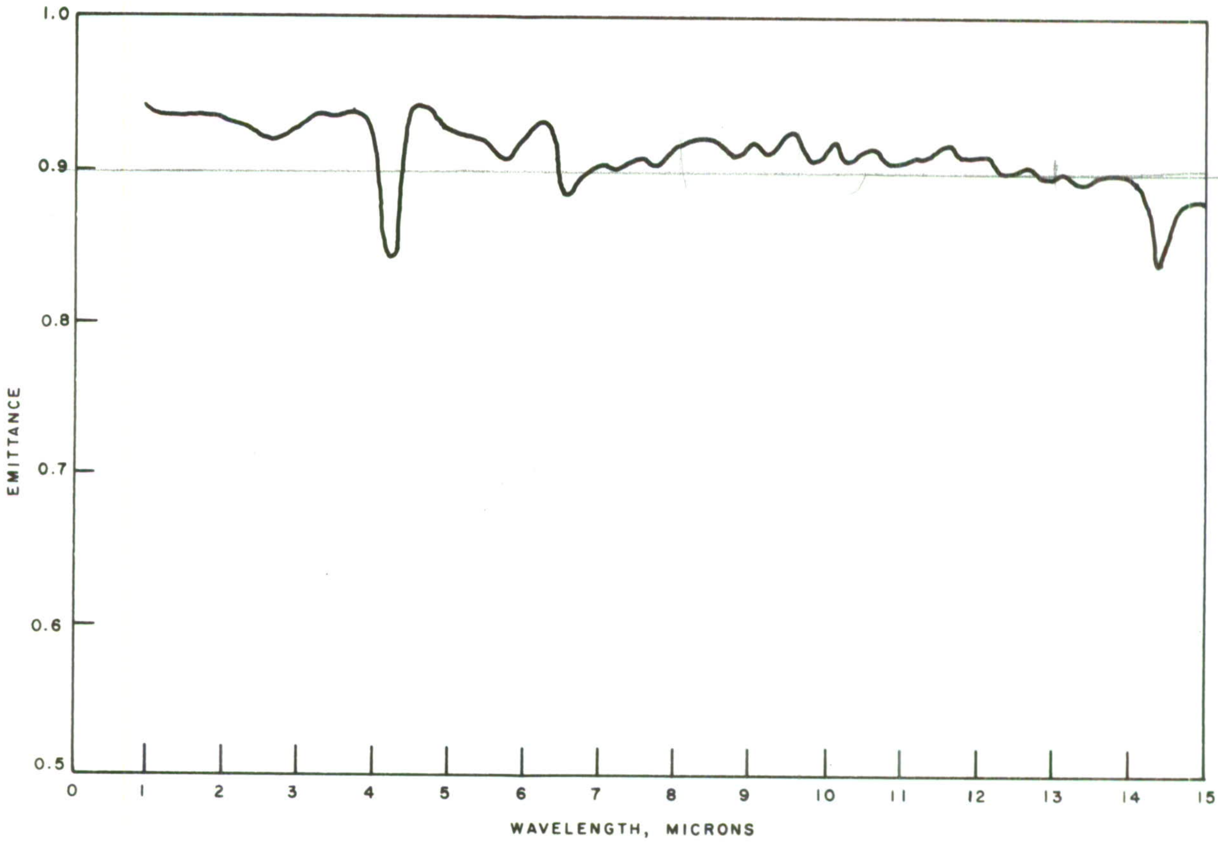

FIG. 75. Spectral Emittance of Glidden Black Enamel.

SPECTRAL EMITTANCE OF RINSHED-MASON BLACK ENAMEL

Test Method

Gier-Dunkle cavity radiator used in conjunction with a Perkin-Elmer Model 83 monochromator.

Form of Original Data Presentation

Authors presented graph of reflectance versus wavelength.

Sample Temperature

Approximately 339°K.

Surface Conditions

Rinshed-Mason black, heat-resistant, air-dry enamel H12144, Type 321 steel backing.

Source

Ref. 3, p. 1409.

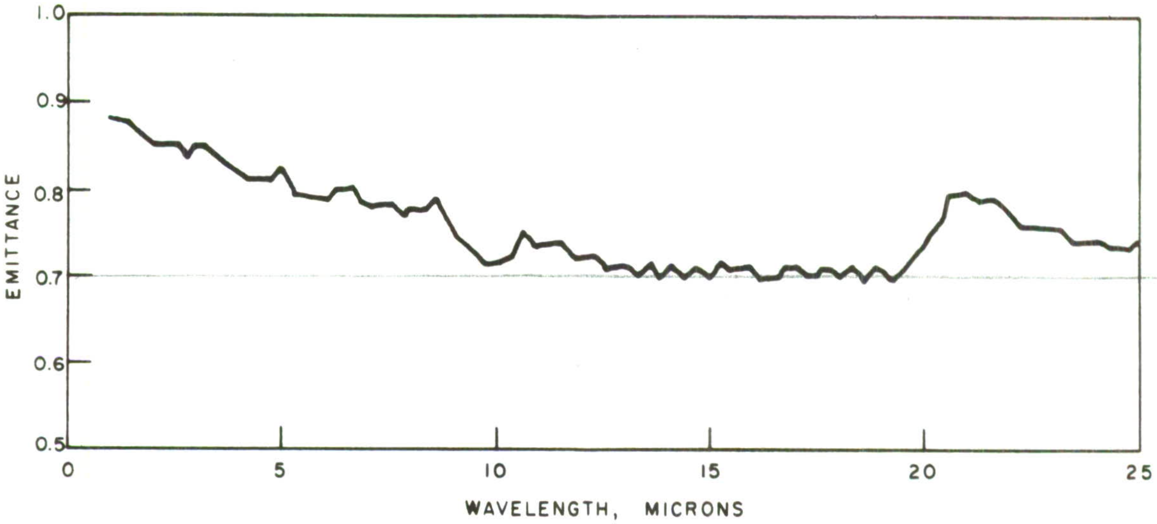

FIG. 76. Spectral Emittance of Rinshed-Mason Black Enamel.

SPECTRAL EMITTANCE OF SERGEANT BLACK PAINT (2024-T3 ALUMINUM BACKING)

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Two coats Sergeant black (MIL-E-10687A) on one coat zinc chromate primer on aluminum backing.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 15.

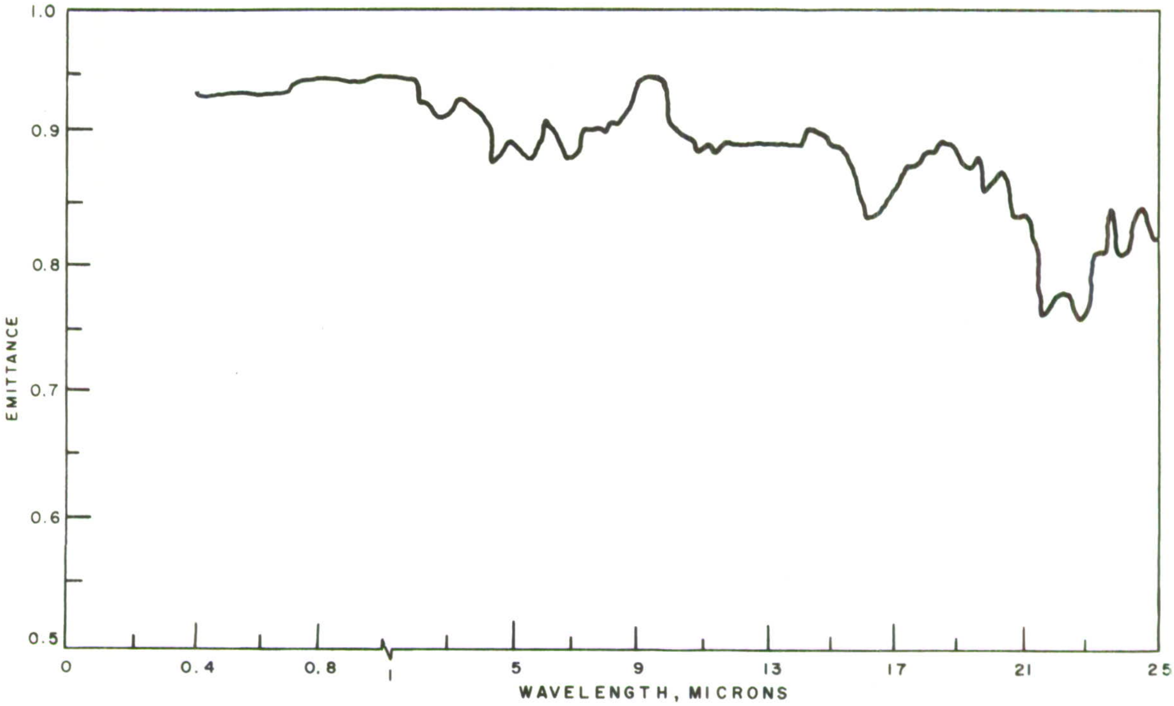

FIG. 77. Spectral Emittance of Sergeant Black Paint (2024-T3 Aluminum Backing).

SPECTRAL EMITTANCE OF SERGEANT BLACK PAINT (AZ 31 MAGNESIUM BACKING)

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Two coats Sergeant black (MIL-E-10687A) on one coat zinc chromate primer on magnesium backing.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 17.

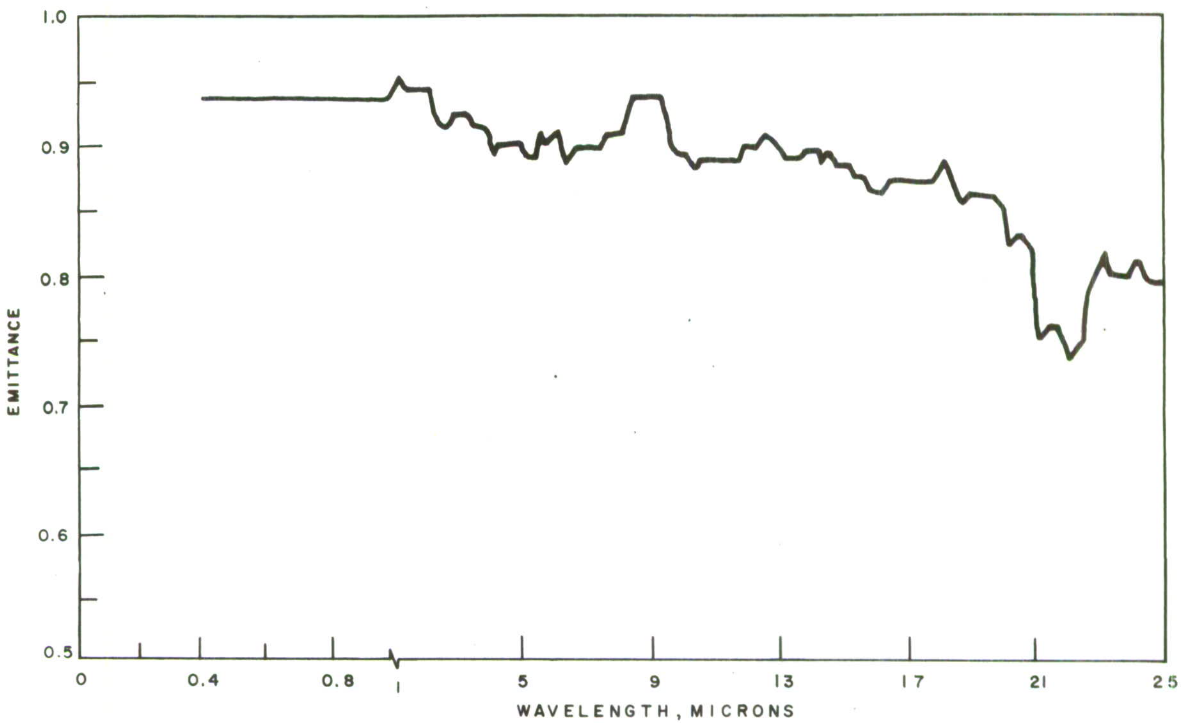

FIG. 78. Spectral Emittance of Sergeant Black Paint (AZ 31 Magnesium Backing).

SPECTRAL EMITTANCE OF SERGEANT BLACK PAINT (GAL-4V TITANIUM BACKING)

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Two coats Sergeant black (MIL-E-10687A) on one coat zinc chromate primer on titanium backing.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 14.

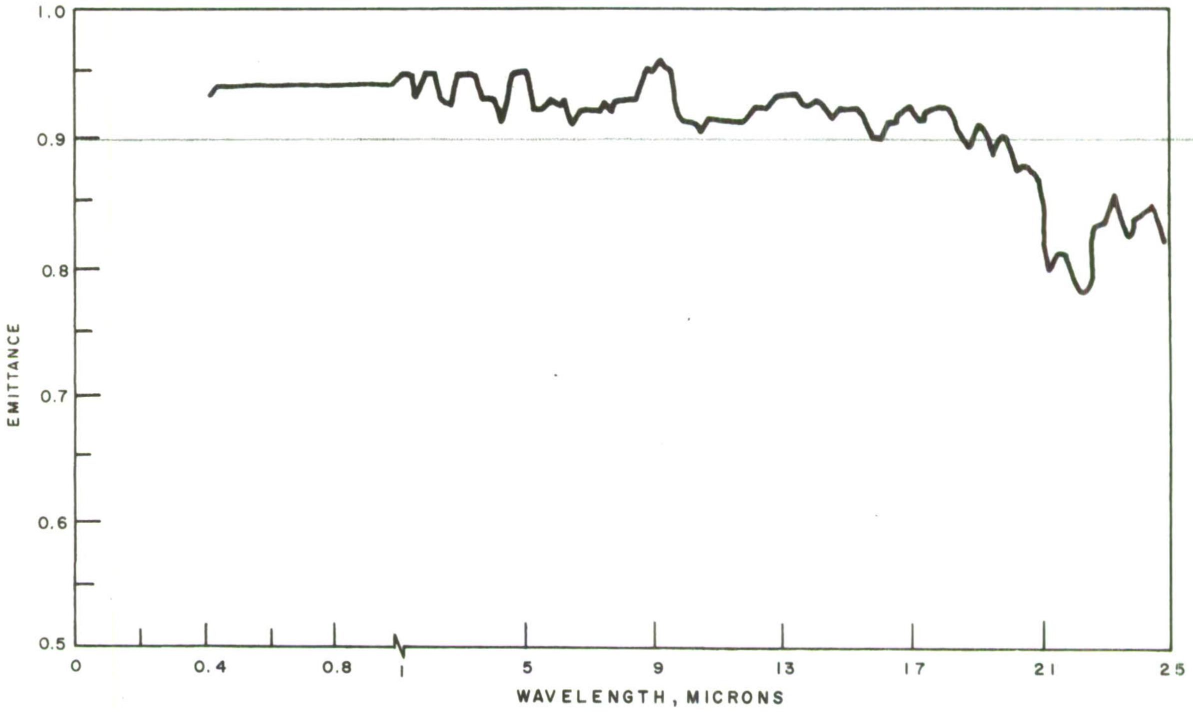

FIG. 79. Spectral Emittance of Sergeant Black Paint (GAL-4V Titanium Backing).

SPECTRAL EMITTANCE OF DU PONT POWDER BLUE PAINT

Test Method

Heated cavity reflectometer used in conjunction with a Perkin-Elmer spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Du Pont Corporation paint sample on a copper cylinder backing.

Comments

Emissivity of copper is small at wavelengths greater than 5 microns. Data presented are conservatively stated to be accurate to within 5%.

Source

Ref. 29, Curve 12.

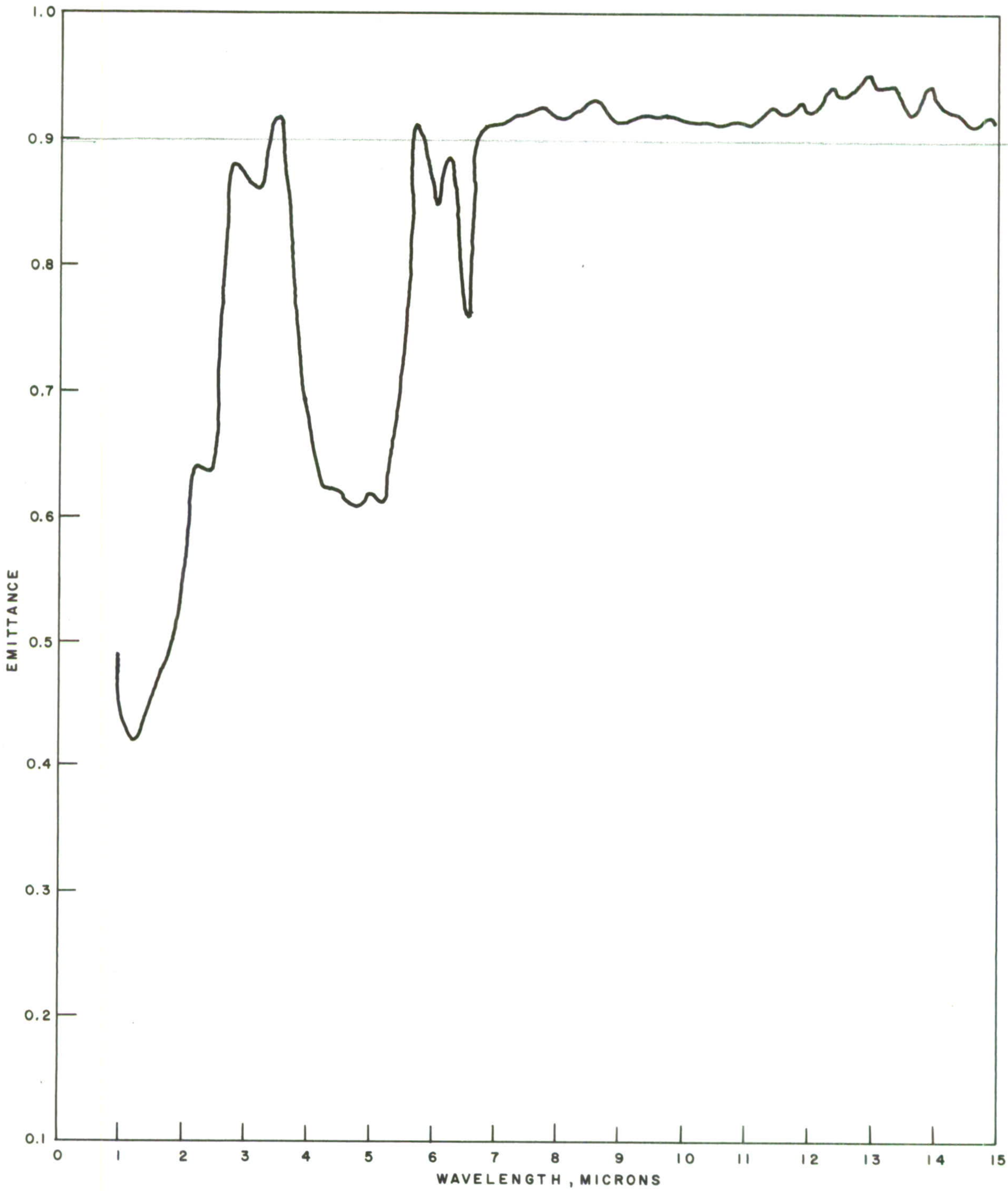

FIG. 80. Spectral Emittance of Du Pont Powder Blue Paint.

NORMAL SPECTRAL EMITTANCE OF SHERWIN-WILLIAMS MAROON ENAMEL

Test Method

Emissivity was calculated from reflectance data obtained with a Perkin-Elmer Model 13 monochromator as a dispersing and detecting system with an auxiliary system of optics.

Form of Original Data Presentation

Authors presented data as shown here.

Sample Temperature

Between 288° and 333°K.

Comments

This graph is an average of 3 samples of titanium coated with Sherwin-Williams aircraft finish, acid resistant enamel, and maroon color #10049 per F5595.

Source

Ref. 15, App. 11.

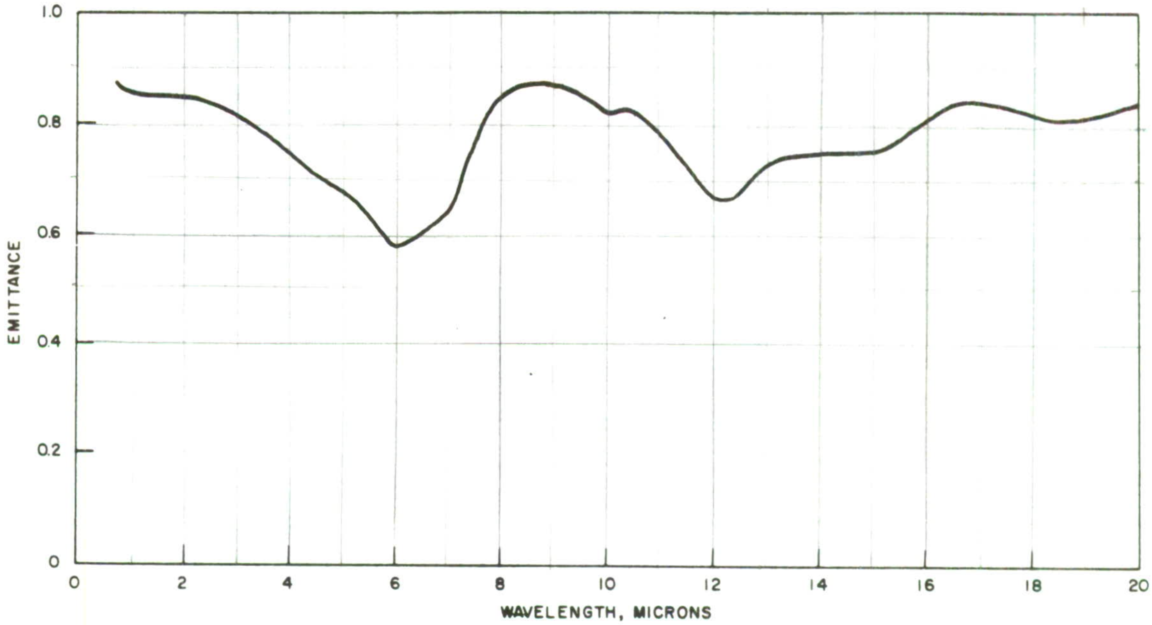

FIG. 81. Normal Spectral Emittance of Sherwin-Williams Maroon Enamel.

SPECTRAL EMITTANCE OF OLIVE-DRAB ENAMELED STEEL

Test Method

An absolute reading spectrophotometer used to compare the test specimen to a Mendenhall Wedge blackbody at the same temperature.

Form of Original Data Presentation

Data presented as shown here.

Sample Temperature

339°K.

Comments

Measurements were made at 0.5 micron wavelength increments.

Source

Ref. 7.

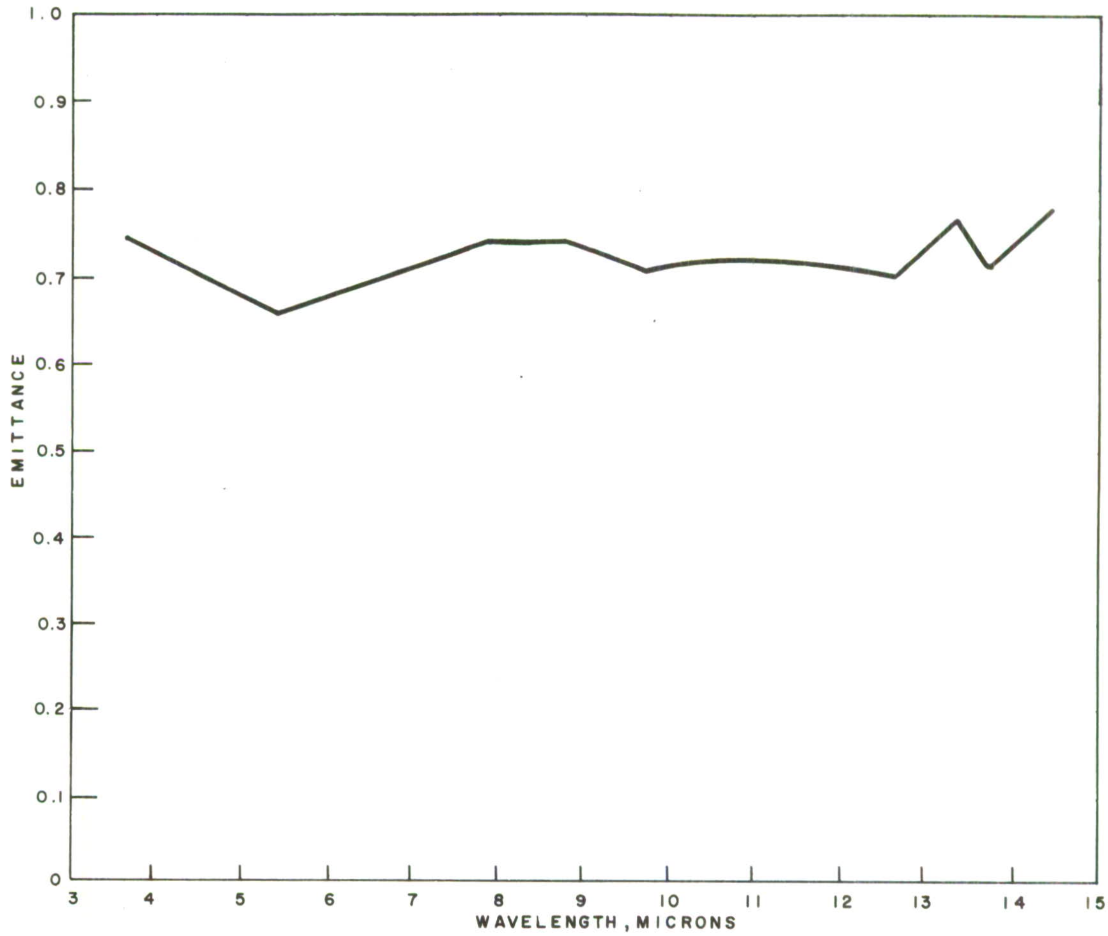

FIG. 82. Spectral Emittance of Olive-Drab Enameled Steel.

SPECTRAL EMITTANCE OF FULLER NEUTRAL AIRCRAFT FINISH

Test Method

Heated cavity reflectometer used in conjunction with a Perkin-Elmer spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Fuller TL-8606 No. 43 Neutral Aircraft Finish, Gray Camouflage Dope Specification 14160a, painted on a copper cylinder.

Comments

Emissivity of copper is small at wavelengths greater than 5 microns. Data presented are conservatively stated to be accurate to within 5%.

Source

Ref. 29, Curve 5.

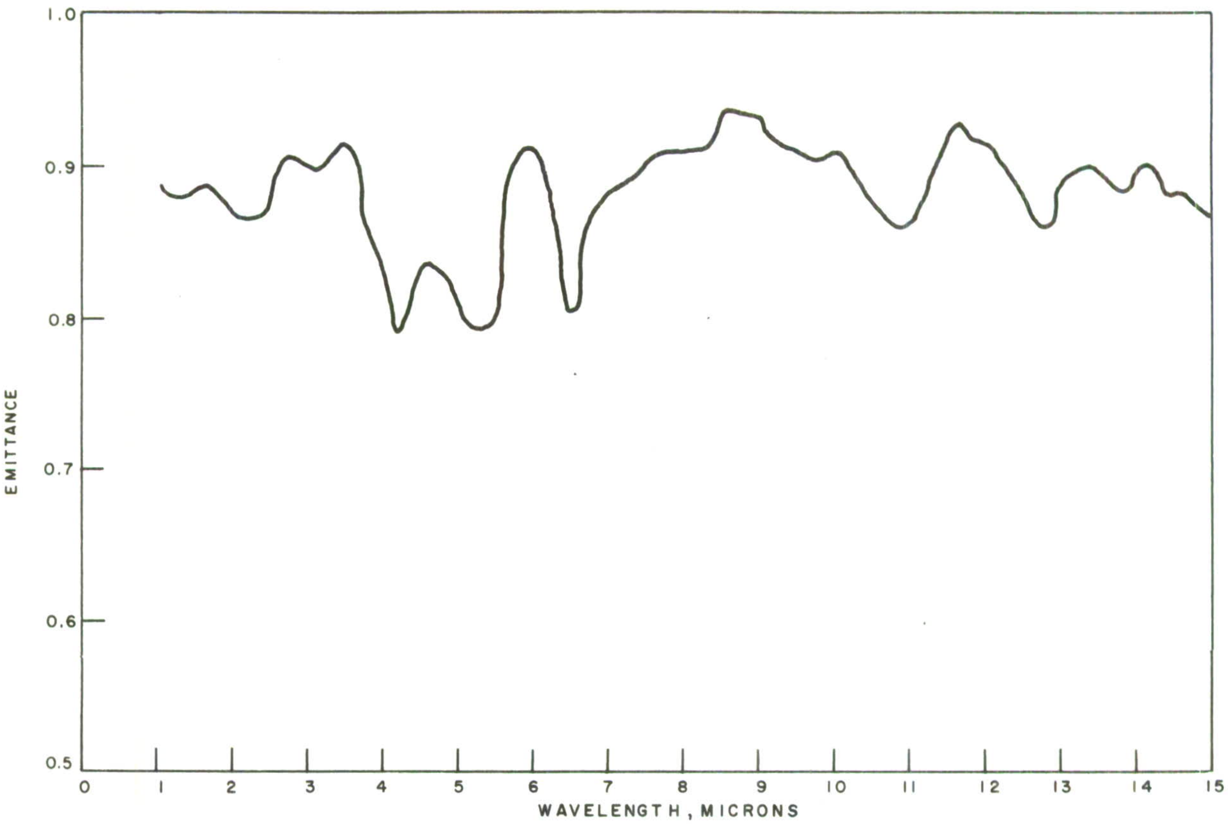

FIG. 83. Spectral Emittance of Fuller Neutral Aircraft Finish.

SPECTRAL EMITTANCE OF WHITE PAINT

Test Method

Heated cavity used as the source of incident radiation. A Perkin-Elmer Model 83 monochromator used as the disperser/detector. Radiation was hemispherically incident and normal reflectance was measured.

Form of Original Data Presentation

Authors presented graph of percent reflectance versus wavelength.

Sample Temperature

Approximately 300°K.

Surface Conditions

White paint (PV-100) on 17-7 PH Stainless Steel.

Comments

Reflectance measurements are in error by no more than 0.02. Measurements were taken each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 22, p. 126.

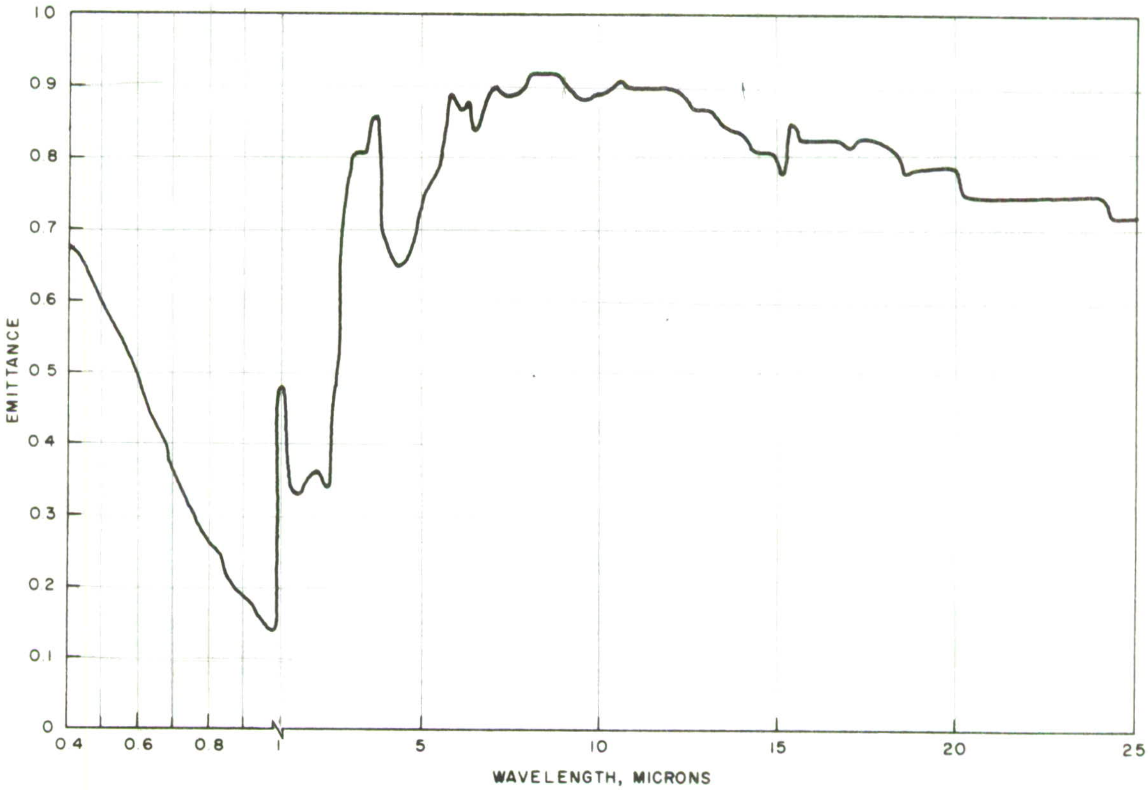

FIG. 84. Spectral Emittance of White Paint.

SPECTRAL EMITTANCE OF PITTSBURGH FLAT WHITE PAINT

Test Method

Heated cavity reflectometer used in conjunction with a Perkin-Elmer spectrometer.

Form of Original Data Presentation

Author presented graph of percent reflectance versus wavelength.

Sample Temperature

Near room temperature.

Surface Conditions

Pittsburgh Flat White Enamel Undercoater, LA 404 painted on copper cylinder.

Comments

Emissivity of copper is small at wavelengths greater than 5 microns. Data presented are conservatively stated to be accurate to within 5%.

Source

Ref. 29, Curve 10.

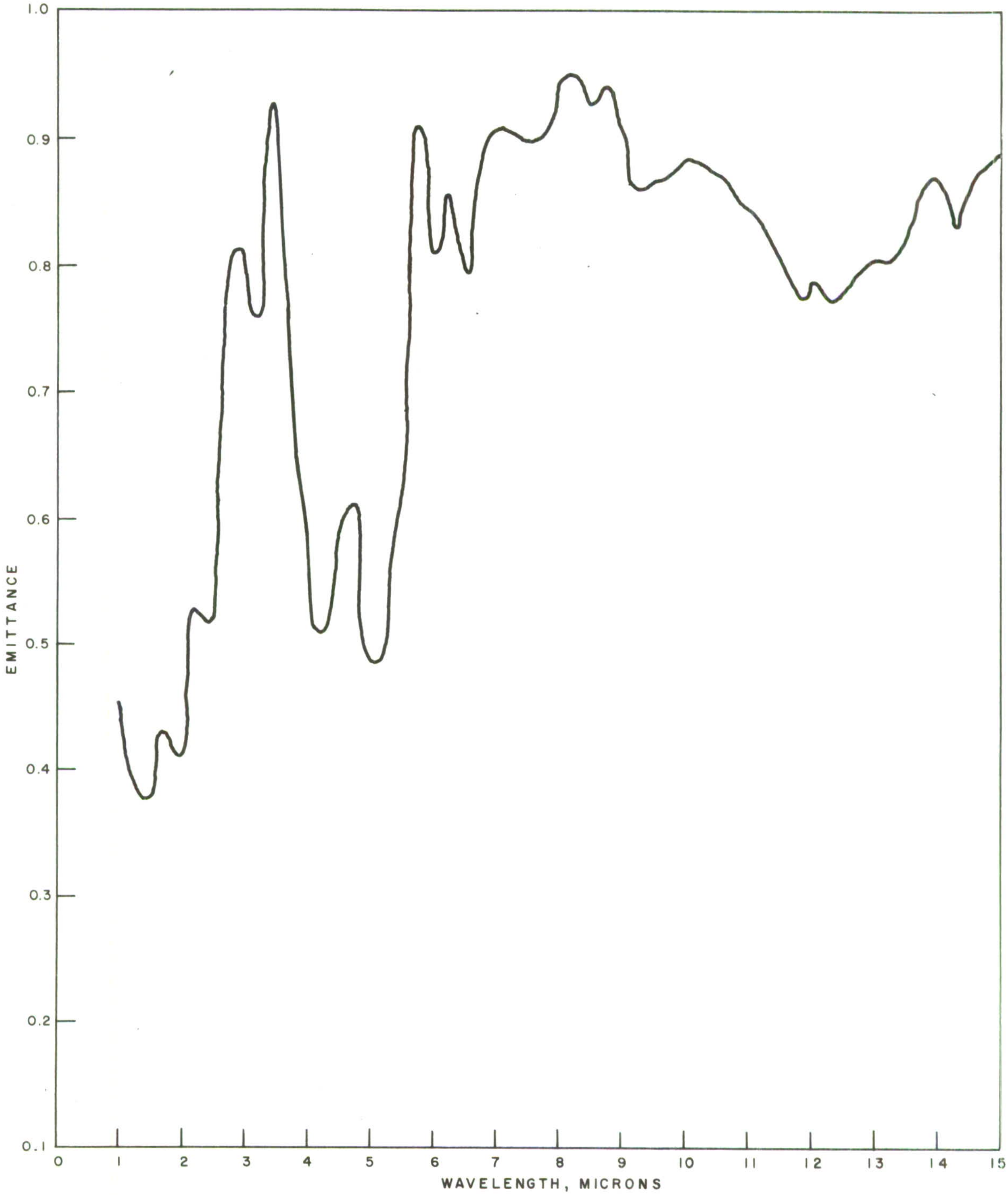

FIG. 85. Spectral Emittance of Pittsburgh Flat White Paint.

SPECTRAL EMITTANCE OF SERGEANT WHITE PAINT (2024-T3 ALUMINUM BACKING)

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Two coats of Sergeant white (MIL-E-10687) on one coat of zinc chromate primer on aluminum backing.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 15.

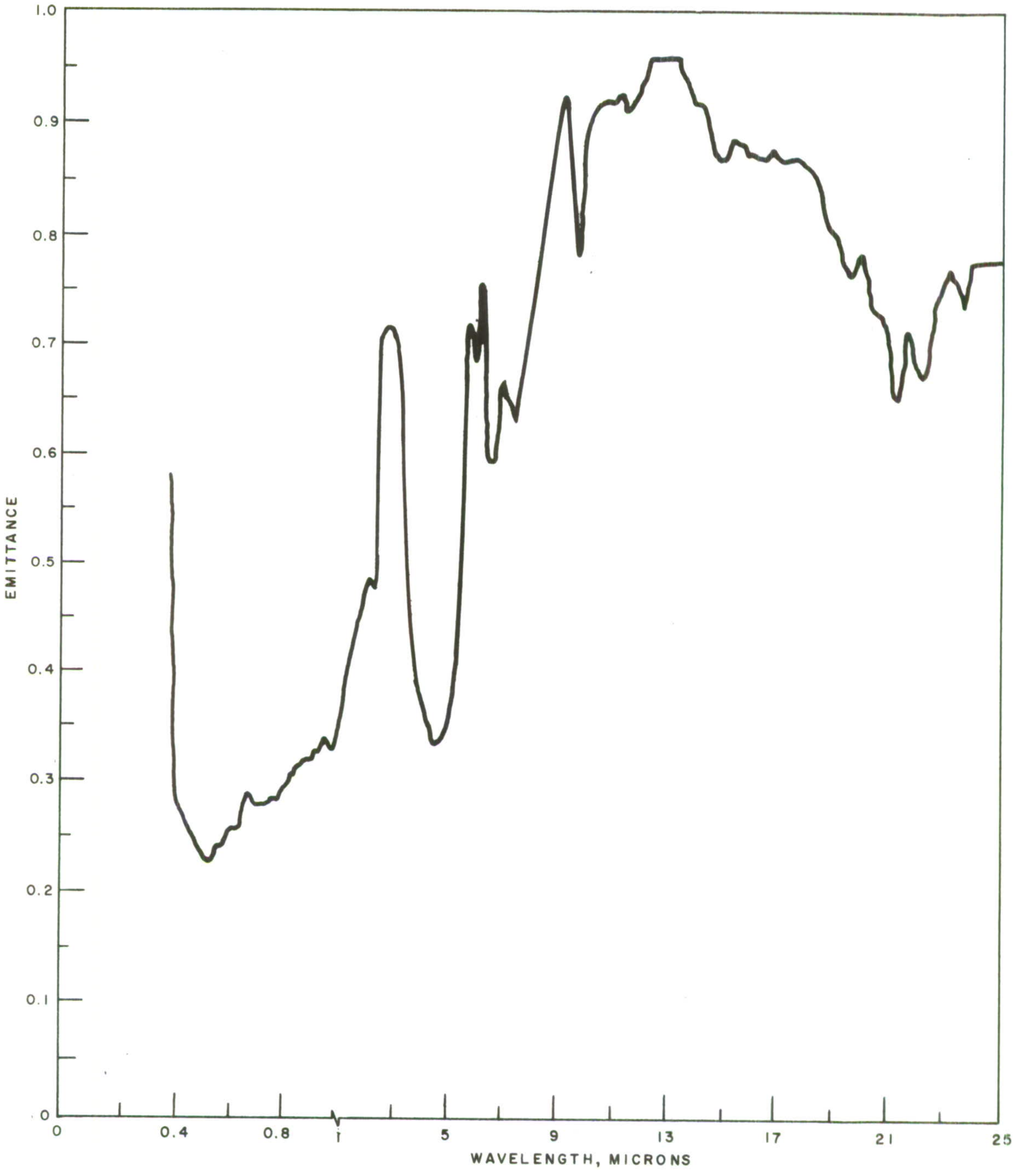

FIG. 86. Spectral Emittance of Sergeant White Paint (2024-T3 Aluminum Backing).

SPECTRAL EMITTANCE OF SERGEANT WHITE PAINT (AZ 31 MAGNESIUM BACKING)

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Two coats Sergeant white (MIL-E-10687) on one coat zinc chromate primer on magnesium backing.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 16.

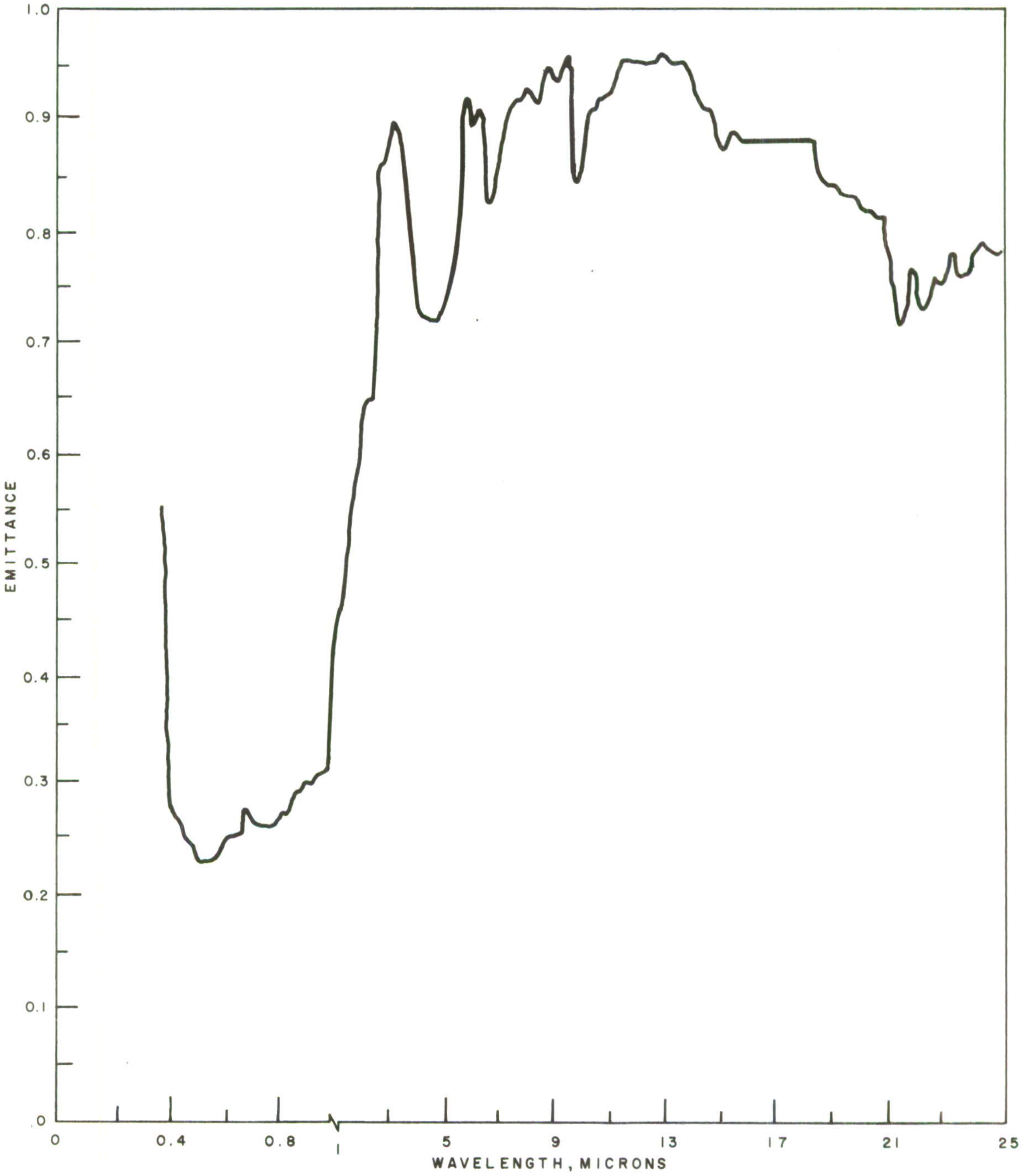

FIG. 87. Spectral Emittance of Sergeant White Paint (AZ 31 Magnesium Backing).

SPECTRAL EMITTANCE OF SERGEANT WHITE PAINT (GAL-4V TITANIUM BACKING)

Test Method

Not mentioned. It was stated that "... reflectances of the sample considered herein were measured by the Electrical Engineering Department of the University of California (Berkeley)".

Form of Original Data Presentation

Authors presented graph of reflectance as a function of wavelength.

Sample Temperature

Assumed to be at or near room temperature.

Surface Conditions

Two coats Sergeant white (MIL-E-10687) on one coat zinc chromate primer on titanium backing.

Comments

Values stated in the authors' reflectance curves were recorded each 0.25 micron between 1.0 and 25.0 microns.

Source

Ref. 4, p. 13.

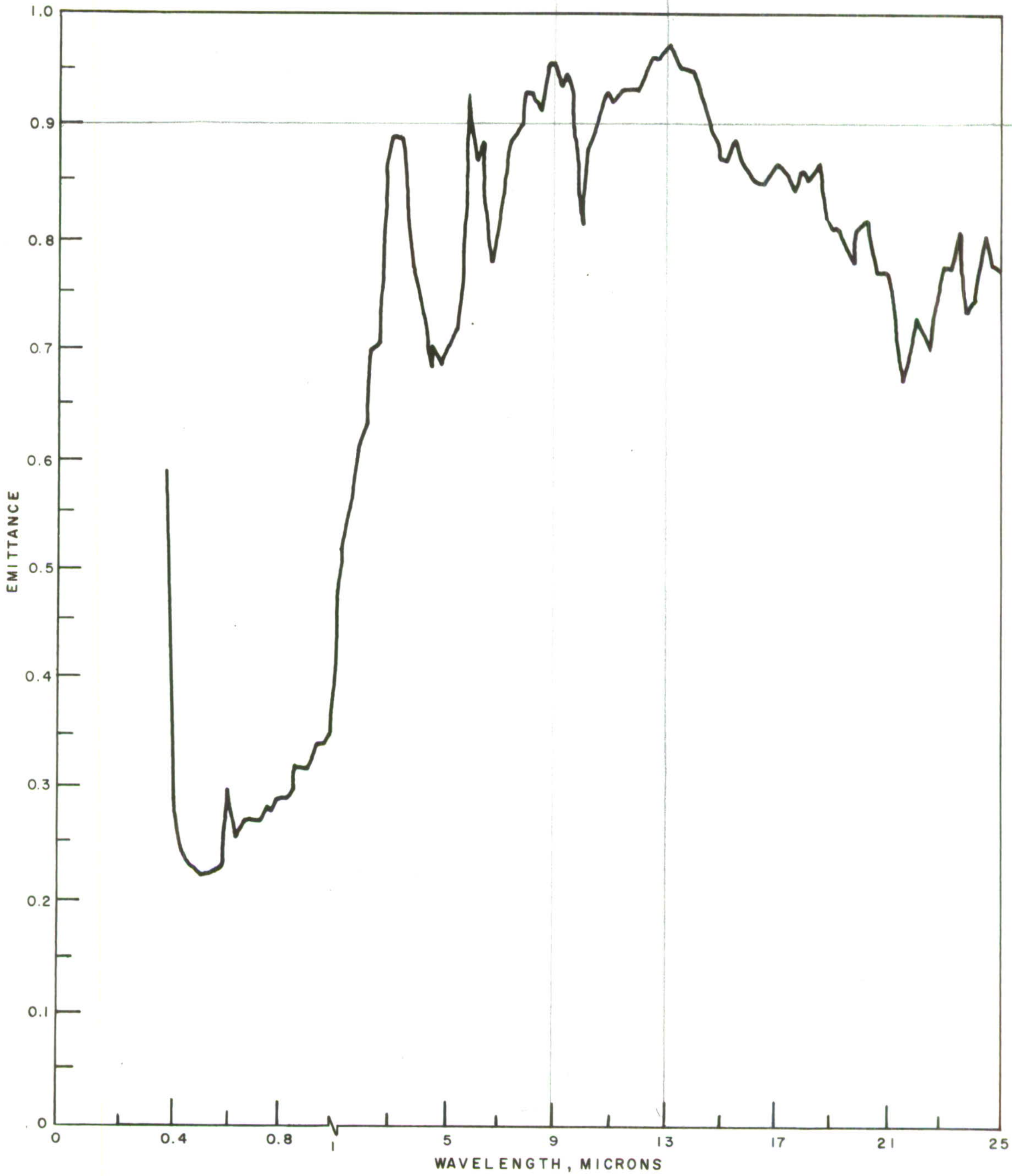

FIG. 88. Spectral Emittance of Sergeant White Paint (GAL-4V Titanium Backing).

BIBLIOGRAPHY

1. Arthur D. Little, Inc. The Thermal Radiation Characteristics of Solid Materials - A Review, by H. N. Blau and others. Cambridge, Mass., March 1958. (Rept. No. 1, Contr. AF 19(604)-2639; DDC AD 146 833.)

2. Bendix Corporation. The Interpretation of Infrared Aerial Reconnaissance Data (U), by G. D. Currie and others. Ann Arbor, Mich., December 1960. (DDC AD 326 623), CONFIDENTIAL.

3. Bevans, J. T., and others. "Comparison of Total Emittances With Values Computed from Spectral Measurements" AMER SOC MECH ENG, TRANS, Vol. 80, Part II (October 1958), pp. 1405-12.

4. California Institute Technology. Radiative Properties of Surfaces Considered for Use on the Explorer Satellites and Pioneer Space Probes, by W. S. Shipley and T. O. Thostesen. Pasadena, Calif., JPL, February 1960. (Proj. ORDCIT, DA-04-495 ORD 18.)

5. Gates, D. M., and C. M. Benedict. "Convection Phenomena from Plants in Still Air," AMER J BOT, Vol. 50, No. 6 (1963), pp. 563-73.

6. Gates, D. M., and others. "Spectral Properties of Plants," APPL OPT, Vol. 4, No. 1 (1965), pp. 11-19.

7. Hayes Aircraft Corporation. Infrared Tank Study: Supplement to the Final Report. Birmingham, Ala., January 1961. (ENG REPT No. 553; Contr. DA-01-009-ORD-916; DDC AD 322 372.)

8. Hovis, Jr., W. A., and W. R. Callahan. "Infrared Reflectance of Igneous Rocks, Tuffs, and Red Sandstone from 0.5 to 22 Microns," OPT SOC AMER, J, Vol. 5 (May 1966), pp. 639-43.

9. Hovis, Jr., W. A. "Optimum Wavelength Intervals for Surface Temperature Radiometry." APPL OPT, Vol. 5 (May 1966), pp. 815-18.

10. Hughes Aircraft Company. Ground-to-Air Scanner Study (U), First Quarterly Report, by J. J. Appel and others. Culver City, Calif., October 1964. (DDC AD 357 705), CONFIDENTIAL.

11. ———. Ground-to-Air Scanner Study. Supplement to First Quarterly Report (U), by J. J. Appel and others. Culver City, Calif., October 1964. (DDC AD 357 705), CONFIDENTIAL.

12. ITT Federal Laboratories. Radiation Properties of Materials - Detailed Refined Measurements, by J. Camus and others. San Fernando, Calif., September 1964. (Contr. AF 04(695)-108, Proj. 5043, TO 50432A.)

13. Library of Congress. Infrared: A Bibliography, Part II, by M. W. Ayton and others. Washington, U.S. Dept. of Commerce, D.C., March 1957. (NAonr 13-47 and NAonr 185-54; DDC AD 122 203.)

14. ———. Infrared: A Bibliography, Part III, by M. W. Ayton and others. Washington, U.S. Dept. of Commerce, D.C., June 1957. (NAonr 13-47 and NAonr 185-54; DDC AD 129 600), CONFIDENTIAL.

15. Lockheed Aircraft Corporation. Spectral and Total Emissivity Apparatus and Measurements of Opaque Solids, by C. Shaw and others. Sunnyvale, Calif., March 1959. (LSMD 48486; Contr. AF 04(647)-97; DDC AD 282 600.)

16. ———. Emissivity: An Annotated Bibliography, By A. A. Beltran. Sunnyvale, Calif., July 1961. (Spec. Bib.: SB-61-38; AF 04(647)-787; DDC AD 263 182.)

17. ———. Optical Absorption and Reflection of Solids: An Annotated Bibliography, by R. C. Gex. Sunnyvale, Calif., February 1962. (Spec. Bib.: SB-61-36; DDC AD 275 021.)

18. Lyon, R. J. P. "Analysis of Rocks by Spectral Infrared Emission (8 to 25 Microns)," ECON GEOL, Vol. 60, No. 4 (1965), pp. 715-36.

19. Martin Company. Measurement of Thermal Radiation Characteristics, by B. T. Replogle. Baltimore, Md., September 1964. (Rept ER 13638; IDEP 428.90.40.60-F2-01.)

20. Minneapolis-Honeywell Regulator Company. Thermal Radiation Properties Survey: A Review of the Literature, by G. G. Gubareff, J. E. Janssen, and R. H. Torborg. 2nd ed. Minnesota, Minneapolis-Honeywell Regulator Company, 1960.

21. New York University. Research, Studies, and Investigations on Spectral Reflectance and Absorption Characteristics of Camouflage Paint Materials and Natural Objects, by M. Kronstein. Research Division of College of Engineering, New York, July 1956. (DDC AD 100 058.)

22. North American Aviation. Spectral and Total Radiation Data of Various Aircraft Materials, by P. E. Ohlsen and G. A. Etenad. Los Angeles, Calif., July 1957. (NA 57-330.)

23. Schocken, Klaus, ed. Optical Properties of Satellite Materials - The Theory of Optical and Infrared Properties of Metals. Huntsville, George C. Marshall Space Flight Center, Ala., March 1963. (NASA TN D-1523.)

24. Shockley, W. G. and others. "Identifying Soil Parameters With an Infrared Spectrophotometer," Proceedings of the 2nd Symposium on Remote Sensing of Environment, 15, 16, 17 October 1962. Ann Arbor, Mich., Infrared Laboratory, Institute of Science & Technology, University of Michigan, February 1963, pp. 267-88.

25. Stanford Research Institute. Evaluation of Infrared Spectrophotometry for Compositional Analysis of Lunar and Planetary Soils, by R. J. P. Lyon, Menlo Park, Calif., April 1963. (NASA TN D-1871; Contr. NASr-49(04).)

26. ———. Evaluation of Infrared Spectrophotometry for Compositional Analysis of Lunar and Planetary Soils, Part II, by R. J. P. Lyon. Menlo Park, Calif., November 1964.

27. ———. Evaluation of Infrared Spectrophotometry for Compositional Analysis of Lunar and Planetary Soils, Part III, by R. J. P. Lyon. Menlo Park., November 1965.

28. Texas Instruments, Inc. Target Signature Measurements Laboratory Study, by D. Andrychuk and M. Benn. Dallas, Texas, (Interim Reports 2 and 3, June 1967 and October 1967.) (Contr. AF 33(615)-5350.)

29. University of California. The Absolute Spectral Reflectivity of Certain Pigments and Metals in the Wavelength Range Between 2 and 15 Microns, by J. T. Gier and others. Berkeley, Calif., February 1949. (Contr. N7-onr-295, Task I.)

30. ———. Spectral Reflectivity of Certain Minerals and Similar Inorganic Materials, by J. T. Gier and R. V. Dunkle. Berkeley, Calif., January 1954. (Contr. DA-11-190-ENG-3; DDC AD 26 394.)

31. ———. Thermal Radiation Properties of Materials, Part II, by R. A. Seban. Berkeley, Calif., August 1962. (WADD-TR-60-370, Part II; AF 33(616)-6630; DDC AD 286 863.)

32. ———. Thermal Radiation Properties of Materials, Part III, by R. A. Seban. Berkeley, Calif., August 1963. (WADD-TR-60-370, Part III; AF 33(657)-7793; DDC AD 419 028.)

33. University of Michigan. IRIA Annotated Bibliography of Infrared Literature. Ann Arbor, Institute of Science & Engineering, Mich., June 1965. (Cumulative reports also used). (Contr. NOnr 1224(52), CONFIDENTIAL.

34. University of Michigan. Emittance and Reflectance in the Infrared: An Annotated Bibliography, by D. E. Crowley. Ann Arbor, Mich., April 1959. (NOnr 1224(12); Rept. No. 2389-15-S.)

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Security Classification

DOCUMENT CONTROL DATA - R&D

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1. ORIGINATING ACTIVITY *(Corporate author)* Naval Weapons Center China Lake, California 93555	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE
COMPILATION OF SPECTRAL EMITTANCES OF BACKGROUND AND TARGET CONSTITUENTS IN THE 8- TO 14-MICRON RANGE

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*
Czarnik, John W.
Leet, H. P.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1968	188	34

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13. ABSTRACT A search of the unclassified literature for 8 to 14 micron spectral emittance information on infrared background and target materials resulted in a comprehensive compilation that is presented in this report. The report abstracts information published prior to October 1967 and concerns the room temperature spectral dependence of the emittance of various classes of materials. A large amount of data is available in the literature for certain material classes such as metals, paint coatings, and minerals, and representative data is here abstracted. Little information is available for the material classes of foliage, soils, plastics, and other synthetic building materials. All useable reported data on these materials is presented. The selection criteria for the inclusion of data is presented. Techniques commonly used to obtain emittance, absorptance, and reflectance data are outlined. A bibliography of open literature reports containing emittance data is presented.

DD FORM 1 JAN 64 1473 0101-807-6800

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